Mass. Department of Public Health
...Report of the State Board of Health on
Water-supply & Sewerage.

SENATE . . . . No. 4.

REPORT

OF THE

STATE BOARD OF HEALTH OF MASSACHUSETTS

ON

WATER-SUPPLY AND SEWERAGE,

UNDER THE PROVISIONS OF CHAPTER 274,
OF THE ACTS OF 1886.

JANUARY, 1888.

BOSTON:
WRIGHT & POTTER PRINTING COMPANY, STATE PRINTERS,
18 POST OFFICE SQUARE.
1888.

Dr. C. F. Chandler
with the kind regards
T. M. Drown

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Commonwealth of Massachusetts.

OFFICE OF STATE BOARD OF HEALTH,
13 BEACON ST., BOSTON, Jan. 9, 1888.

HON. HALSEY J. BOARDMAN, *President of the Senate.*

SIR: — I have the honor to present to the Legislature the Report of the State Board of Health, required by the provisions of section 1 of chapter 274 of the Acts of 1886, entitled "An Act to Protect the Purity of Inland Waters."

Respectfully, your obedient servant,

SAM'L W. ABBOTT,
Secretary State Board of Health.

WATER SUPPLY AND SEWERAGE.

REPORT OF THE STATE BOARD OF HEALTH REQUIRED BY SECTION 1 OF CHAPTER 274 OF THE ACTS OF 1886.

The work of the State Board of Health under the "Act to protect the purity of inland waters," and under the appropriation of $30,000 made by the last General Court, may be divided into three departments: —

I. That of advising cities, towns, corporations and individuals in regard to the most appropriate source of supply for their drinking waters and the best method of assuring the purity thereof and of disposing of their sewage.

II. Obtaining information in regard to all of the existing sources of domestic water supplies in the State, and subjecting samples from each source to chemical analysis once a month, and to biological examination when necessary, and in making such chemical examinations of other inland waters as the general purposes of the Act require.

III. Collecting information in regard to experiments that have hitherto been made upon the purification of sewage by applying it to land, and arranging for and conducting such additional experiments upon such purification as are necessary to obtain knowledge required for immediate use within the State.

I.

In the first department there have been twenty-five applications* from the following cities, towns and individuals for advice or official action by the Board. Of these, eleven were in regard to water supplies, as follows: Boston, Chelsea, Somerville and Everett; Bradford, Randolph and

* Blank forms of application for advice under the provisions of chapter 274 of the Acts of 1886 have been prepared for the use of cities, towns and others, and may be procured at the office of the Board at 13 Beacon Street, Boston.

Holbrook, Andover, Ayer, Belmont, North Easton, Maynard, Needham, Athol, Mansfield. There were also eleven applications in regard to sewerage: from Taunton, Milford, Ware, Westfield State Normal School, Westborough Lunatic Hospital, Clinton, Brockton, Southbridge, Athol, Reformatory Prison for Women, Waltham. Two applications in regard to pollutions of streams: Arlington, relating to pollution of Alewife Brook and Lower Mystic Pond, and Palmer, in regard to pollution of Graves Brook, and one application from W. H. Abbott, concerning the disposal of manufacturing refuse at Northampton.

To satisfactorily answer the questions submitted to the Board, under the provisions of chapter 274 of the Acts of 1886, the Board has adopted the following practice: The plans and estimates presented by the parties in interest are at once referred to the engineer of the Board, in order that he may make a careful examination of the localities concerned and determine the value of the evidence already collected. Should this be sufficient to enable him to come to a conclusion satisfactory to himself, the result is reported to the Board. The appropriate committee, and in many instances the whole Board, then visits the locality. The advice of the consulting engineer is also obtained in all important cases; and public hearings are held whenever it seems probable that useful information can be obtained in this way.

The Board has not held it to be a part of its functions to prepare original plans, and has carefully avoided any interference with the work properly belonging to the engineers employed by the parties making application.

The responsibilities in carrying out the provisions of this Act are, as will be seen by the above statement, no less than those of the parties directly interested, nor can they be properly performed except after mature consideration, with the advice of thoroughly educated experts.

Water Supply.

The application of the Boston Water Board in behalf of the cities of Boston, Chelsea and Somerville and the town of Everett, in regard to taking the Shawsheen River as a source of supply for these communities, was presented to the

Board of Health on the 19th of January, and occupied the attention of the Board and nearly all the time of its engineer and assistants for more than two months, with careful revision by its consulting engineer. The fundamental questions of the probable growth and future needs of these communities were thoroughly investigated, and with the cordial co-operation of the Water Board of Boston, through their engineers, in supplying data in their possession, the quantity of water that can be depended upon from the present sources of supply of the city of Boston was ascertained from their latest surveys and complete records; and the comparative cost of future maintenance of the supply to these communities from the different sources was determined. It was concluded by the Board of Health that it was not only for the interest of all parties holding property within the valley of the Shawsheen River, but also largely for the interest of the city of Boston and the communities associated in her application, that the present sources of supply controlled by the city of Boston were and would be for many years the most appropriate source of supply for these communities, and on the 6th of April the following communication was made to the Boston Water Board: —

State Board of Health, 13 Beacon Street,
Boston, April 6, 1887.

Col. Horace T. Rockwell, *Chairman of the Boston Water Board.*

Dear Sir: — The State Board of Health has had in careful consideration the scheme of taking water from the Shawsheen River for the use of the cities of Boston, Chelsea and Somerville, and the town of Everett, which you, in their behalf, presented on the 19th of January in accordance with chapter 274 of the Acts of 1886.

The purpose of this Act bearing upon the proposed scheme is, that this Board shall consult with and advise you whether this is the most appropriate source of supply, having regard to the interests of all who may be affected thereby.

In considering this question we have made a careful investigation of the present and future needs of the communities which you represent, and the amount of water which can be depended upon from the sources of supply which have by the State been put under your control.

The conclusions already reached, differing in some respects from those presented by you, have so important a bearing upon the general consideration of the subject that we now present them as the basis for further consideration.

From a careful study of the experience of Boston and other places made by our chief engineer (the details of which upon this point or upon others which may arise he will, if you desire, explain to you or to your engineer), he reaches the conclusions, which we regard reasonable and well founded, that with careful and business-like restriction of waste the consumption of water within the district supplied by Boston in 1895 may be reduced to 66 gallons per inhabitant; and to provide for the increasing yearly use for the next forty years four-tenths of a gallon per year should be added to 66 gallons for the quantity to be supplied for each succeeding year, making the estimated consumption of water per inhabitant in this district as follows: —

1895, ...	66 gals. per inhabitant.
1900, ...	68 " " "
1905, ...	70 " " "
1910, ...	72 " " "
1915, ...	74 " " "
1920, ...	76 " " "
1925, ...	78 " " "
1930, ...	80 " " "

The population of the district now supplied with water from the Boston Works has been as follows since 1840: —

YEAR.	Population.	Increase in Five Years.
1840, ...	122,646	–
1845, ...	157,836	35,190
1850, ...	193,027	35,191
1855, ...	232,663	39,636
1860, ...	268,916	36,253
1865, ...	292,382	23,466
1870, ...	327,951	35,569
1875, ...	388,175	60,224
1880, ...	413,713	25,538
1885, ...	451,898	38,185

From a careful study of the growth of the whole district and of its several parts, we find it reasonable to conclude that the future growth will be nearly as follows: —

YEAR.	Population.	Increase in Five Years.
1890, ...	493,100	41,202
1895, ...	534,900	41,800
1900, ...	577,300	42,400
1905, ...	620,300	43,000
1910, ...	663,800	43,500
1915, ...	707,900	44,100
1920, ...	752,600	44,700
1925, ...	797,900	45,300
1930, ...	843,800	45,900

The sources of supply now used for this district are Cochituate Lake, Sudbury River and Mystic Lake. The latter drains an area which has a population of about 800 per square mile. The amount and present rapid increase of this population, together with the character of the refuse from many manufacturing establishments, indicates the probable necessity of the future abandonment of this source of supply, and we confine our consideration to the Cochituate Lake and Sudbury River sources. The quantity of water which can be depended upon from these two sources, when all of the storage basins which the city of Boston proposes to build are completed, has been the subject of careful study by our engineer, based upon the quantity that was derivable in the series of years 1880 to 1883, when the yield of the streams was very much lower than ever before known, with the results of a net daily yield from these sources of 56,000,000 gallons during the driest year.

From this quantity there is to be deducted 1,500,000 gallons, which the law requires should be allowed to run down the river daily; 2,700,000 gallons daily which the towns upon the Sudbury and Cochituate watersheds will, it is estimated, have the right to draw from these sources, and deducting also 1,800,000 gallons for unforeseen contingencies, we have 50,000,000 gallons available daily, during the driest year, for the use of the city of Boston. This quantity will be sufficient to supply the estimated population of Boston, Chelsea, Somerville and Everett with 72.8 gallons per inhabitant until 1912, and will supply the estimated population of the present territory of the city of Boston with 80 gallons per day per inhabitant until 1925. Having reached these results from a careful consideration of the actual existing conditions, this Board is constrained to advise that the most appropriate source of supply for a term of years for the district which you represent is the territory already under the control of the city of Boston in the Cochituate and Sudbury River areas. If these, our conclusions, are borne out by the experience of Boston, Chelsea, Somerville and Everett, although the Mystic be abandoned, the city of Boston can from the other sources under its control supply these communities, and need not, for quantity of water, seek a new source for fifteen years at least, and then there will be ten years for construction of works before the additional quantity will be needed.

We would add that, from such examination as we have been able to make, pecuniary considerations are in the opinion of the Board largely in favor of the development of the Cochituate and Sudbury River sources to their full extent before introducing a new source. By order of the Board,

SAMUEL W. ABBOTT, *Secretary.*

BRADFORD. — The selectmen of Bradford, by letter dated Feb. 2, 1887, asked the advice of this Board with reference to two ponds which they thought might be suitable as a source of water supply. These were Johnson's Pond in the towns of Groveland and Boxford, and Mitchell's, or Hovey's Pond, in the latter town. The ponds were examined by our engineer and samples of their waters were taken for analysis; but the time of taking the samples being that of high water from spring rains they were not regarded as conclusive. The Board replied on March 2 that —

While no evidence is presented by such examinations that the quality of the water, either of Johnson's or of Mitchell's ponds, is at this time objectionable, the Board is unable without further examination, which would extend until after your March town meeting, to give a definite judgment as to the appropriateness of these ponds for your water supply.

RANDOLPH AND HOLBROOK. — The joint boards of Water Commissioners of these towns, on the 23d of February, submitted their plans for taking the water of Great Pond, lying partly in Randolph and partly in Braintree, for a joint water supply. It was proposed to pump the water into iron water towers, one to be situated in each of the towns to be supplied.

After carefully examining the surrounding country to see if some of the objections to this source could not be avoided, the following advice was given : —

The State Board of Health has by its engineers examined the available sources of water supply for the towns of Randolph and Holbrook, and considering their present population and probable growth has been unable to find a more appropriate source of supply than the proposed source, — Great Pond in Randolph and Braintree. This source has, however, unfavorable characteristics which demand attention. Upon its watershed live about one quarter of the inhabitants of Randolph, nearly 1,000 people, whose sewage should be kept out of the pond. From about one-half of these houses the sewage can at reasonable expense be turned into the watershed in the south-easterly part of the town and be disposed of with the sewage from that quarter. The remaining sewage in the drainage area of the pond should be effectually filtered, or otherwise purified, so that it will not be detrimental to health before being turned into the pond or into any of its tributaries.

Andover. — The committee on water supply of this town notified the Board that a petition had been presented to the Legislature of 1886 for authority to take a water supply from any source within the limits of the town, and that the petition had been referred, by that body, to the Legislature of 1887, where it was then pending. The large number of cases relating to water supply and sewerage having precedence of this one prevented its consideration until the action of the Legislature, in granting the petition, made it unnecessary for this Board to act until the question should come to them in more definite form.

Ayer. — The Water Commissioners of this town, June 20, 1887, asked the advice of this Board as to two proposed sources of water supply. They also asked if *subsoil* waters had been found more satisfactory throughout the State than *pond* waters. The sources submitted were

Sandy Pond, said to have an area of about seventy-five acres, and a proposed well near a mill-pond. The advice contained in the reply of the Board, given below, with regard to storing waters *collected from the ground* in dark, covered reservoirs, was based largely upon the experience of cities and towns in this State, which was at that time being gathered in connection with the systematic examination of all of the public water supplies. Further returns received, and the result of chemical and biological examinations since made, emphasize the need of following this advice: —

In response to your request to know whether subsoil waters have been found more satisfactory than pond waters we give you a summary of results reported to the Board up to the present. Of seven places which collect ground water and store it in open earthen and masonry reservoirs, three report trouble, and four report no trouble. Of fourteen places so collecting and pumping into iron or masonry tanks, some of them covered, two report trouble, one which shows by analysis to be poor before being stored, and twelve places report no trouble. The surface water supplies, including both ponds and storage reservoirs, have given more trouble east of the Connecticut River than west of it in the mountainous region. Up to the present time the ground water supplies have given less trouble than surface water supplies, and the ground water supplies are far more satisfactory when used directly after being drawn or with as little storage as practicable.

The samples of water submitted from both of the sources of supply are of satisfactory quality; that from the flowing well is unusually satisfactory. The information furnished is not sufficient for determining whether a sufficient quantity can be obtained from the proposed wells or not. If assured of the necessary quantity the Board would advise adopting the supply from wells, and to avoid deterioration when stored in open reservoirs such water as cannot be conveyed directly from the wells to the consumers should be stored in a dark, covered reservoir, made as small as practicable. A second and larger reservoir may be necessary as a resource in case of fire or other emergency.

BELMONT. — The Water Commissioners, on the 28th of June, 1887, gave notice of their intention to take water from the Watertown Water Supply Company. The proposed source being an established water supply which had been examined by the Board and found of suitable quality, notice to this effect was sent to the Commissioners.

North Easton. — The Board of Water Commissioners in July submitted outlines of proposed plans of water supply for the village of North Easton. It was proposed to collect a supply of ground water from a well to be sunk in a meadow not far from one of the mill-ponds on the Queset River.

The matter was examined and the source which they had selected approved, with the further advice that in case of insufficient quantity an additional supply should be sought from underground sources and connected with the proposed system without exposure to light.

Maynard. — In the application presented to this Board, August 15, 1887, by the committee on water supply of the town of Maynard, the statement is made that the committee are authorized to investigate the question of water supply for the town, and to petition the Legislature, to be convened in 1888, for permission to take the waters of White Pond, situated in the towns of Hudson and Stow about two and one-half miles south-west of the site of a proposed pumping station in the town of Maynard. The committee asked the advice of this Board as to the most appropriate source of supply for the town, and particularly as to the source selected by them. This source has been examined by our chief engineer, and an analysis of the water has been made. The sufficiency of the supply as regards quantity is not so obvious that it can be determined from such examinations as we think it practicable for our engineer to make, and the committee have been asked to employ an engineer to make surveys and furnish more definite information upon this point.

Needham. — The water committee of this town asked the advice of the Board in regard to two sources for the supply of ground water, which they had been investigating. The Board advised that the danger of pollution within the Rosemary Valley was so great that this source should be rejected; also, for the same reason, water should not be taken from that portion of the valley containing Colburn spring, west of Dedham Avenue.

The area east of Dedham Avenue appears suitable at present, but may not continue of satisfactory quality with the growth of the town, and the Board advised further examination for a filter gallery on the bank of Charles River, to be used in connection with this supply or distinct from it.

ATHOL. — In the application presented to this Board by communication dated Nov. 18, 1887, the statement is made that the town has voted to petition the next Legislature for the right to take water, for domestic and other purposes, from Phillipston Pond in the town of Phillipston.

The committee of the town of Athol who have this matter in charge ask the opinion of this Board as to whether this pond will furnish a sufficient quantity of water of good quality to supply the town in years to come. The proposed source and others in the vicinity of Athol have been examined by our engineer and the matter is now under advisement.

MANSFIELD. — The Board of Water Commissioners of the Mansfield Water Supply District on the 12th of December, 1887, gave notice to this Board of their intention to introduce a system of water supply, and submitted outlines of their proposed plans. The investigations in this case have not yet been made.

ADVICE IN REGARD TO DISPOSAL OF SEWAGE.

TAUNTON. — On Dec. 13, 1886, the Sewerage Commission of this city submitted a report containing their conclusions as to the best method of disposing of the sewage of the city.

Briefly stated, they report that Mill River, which at present receives the sewage of the city and the drainage from gas works, etc., is at times offensive, and that, to prevent offence, it is desirable to straighten and wall the stream, to make the bottom concave, to remove the lower dams, and to obtain the control of the water of one or more mill privileges for the purpose of flushing; with these things carried out, they believe the river can carry the sewage of the city for a long time to come.

On Feb. 4, 1887, the Board sent the following reply : —

That from the reports of its engineers of the results of their examination of the ground which was visited in company with the Sewage Commission of the city, this Board does not approve of the proposed system of sewage disposal for the city of Taunton.

MILFORD. — The town of Milford, through their engineer, Mr. Ernest W. Bowditch, submitted plans for the disposal of the sewage of the town by filtration through land, the effluent from the filter beds to go into the Charles River. Mr. Bowditch appeared before a committee of the Board and explained the proposed scheme. After due consideration the Board replied that —

In their opinion it is not desirable to locate a filtration ground on the banks of a stream which supplies water for domestic use, and as Milford is upon such a stream, but also adjacent to a drainage area not so used, the Board suggests that examination be made to determine whether a suitable filtration ground may not be found in the drainage area not used for a domestic water supply. If, however, the filtration ground must be located in the drainage area used for a domestic water supply, it is regarded as undesirable to have its effluent discharge directly into the river, and preferable to select a ground which is distant from the river, that any effluent from the ground not properly filtered may be recognized, and prevented from entering the river.

WARE. — The Road Commissioners submitted to the Board, March 19, 1887, two plans made by different engineers for the sewerage of the town. Both plans proposed to discharge the sewage into the Ware River. The Board advised the town to have plans prepared for a system of sewerage providing for the separate removal of sewage and storm-water, and to have the cost estimated for comparison with the cost of the system proposed by the present plans.

In the latter part of July an outline of a proposed system of sewerage, in which storm-water and sewage are to be kept separate, was submitted to the Board. After giving a hearing to the town and to others interested, the Board gave the following advice: —

The State Board of Health having given a hearing to the town of Ware and others interested in the disposal of its sewage, and having considered the plan of sewerage presented, renew their recommendation that the separate system of sewerage be adopted in order that, should it prove necessary in the future to purify the sewage before turning it into the river, it can be done with reasonable expense.

With such system, and the understanding that the turning of crude sewage into the river may in time prove detrimental to the needs and interests of this or other communities, and it will then be otherwise disposed of, the Board approves of the general method of disposal presented.

In regard to advice asked upon details of the system to be adopted, the Board finds the plan presented so incomplete that it cannot serve as a basis for such advice.

The economy and efficiency of a separate system of sewerage depend so much upon the proportion of parts to the work required of them, and the design and arrangement of details, that much more study should be expended upon these subjects than the present plans indicate.

The plans should comprise a general plan, with drainage districts shown upon it, profiles of each street showing sewers with sizes and grades, and the locations of all cellars in the business portions, or in other places where they may be difficult to drain. The plans and profiles should also show the location of manholes and flushing chambers. Details should be made showing designs of brick sewers, manholes, flushing chambers, catch basins, etc., and of the river outlets and works to protect them.

A report should be made by the engineer, describing the system and how it is to be operated, and giving the estimated cost of the whole system, and of such a portion of it as would be desirable to build at first.

Upon receiving such plans the officers of the Board will examine and advise if any changes are desirable.

State Normal School at Westfield. — The following letter contains a statement of the condition of the drainage at the State Normal School at Westfield, indicated in the application of the Committee on Education of the Legislature, together with the advice of the Board relative to the same: —

To the Chairman of the Committee on Education.

Dear Sir: — The State Board of Health received from Mr. Foote, the secretary of the committee on education, a plan of a proposed sewer in School Street, Westfield, — with the proposed Act, House Document No. 195, — with the request from said committee that the State Board of Health would examine and report to the committee if the plan proposed be the best method of relieving the State Normal School and Boarding Hall of the ill effects which they experience from the present condition of drainage in their vicinity. The method proposed is to build a two feet by three feet brick sewer through School Street, from where the town brook crosses this street to the south side, to where it re-crosses to the north side, a distance of some 700 feet, turn the brook through this sewer and cut off all that part of the brook which lies south of School Street, and then drain the State buildings into the sewer. The most important objects affecting the State property being to remove the unwholesome brook with open walls, now used as a sewer, which runs directly under the cellar of the Normal School Boarding Hall and to drain the two State buildings. The State Board of Health has examined this matter by its committees and by its engineer, and while other plans for accomplishing the desired result at the State buildings, such as replacing the open walls of the brook through the lot of the Boarding Hall by a thirty inch iron pipe with tight joints and a sufficient pipe sewer from the school building down School Street to the brook, have presented some advantages over the one proposed in the bill, the Board has upon further consideration been obliged to conclude that neither of these methods presents an adequate or permanent relief to the State buildings and the territory adjacent and along the valley of this brook. This brook extends for a third of a mile below the proposed sewer as a sluggish ditch winding through barnyards, and under buildings, much obstructed by sewage débris, the flow from adjacent privies and from street and yard surfaces, and is the general receptacle of anything which people wish to get rid of; the walls are falling in and are being crowded nearer together by frost; the bottom is filled with one foot or more of decaying material which upon being stirred sends up foul gases. It will be evident upon consideration that a sewer seven hundred feet long, replacing eight or nine hundred feet in length of such a brook, in which distance the fall in the brook is about one foot, will not in its middle section reduce to an appreciable extent the level of water standing in the ground adjacent, and in time of heavy rain upon the 314 acres drained by this brook above Washington

Street the cellars which have been flooded by this brook are still to be flooded; and the small culverts up the stream which now hold this water back in ponds after heavy rains will naturally be enlarged from time to time, bringing the water down the valley after a rain more freely and causing increased flooding of cellars.

The large drainage area of 314 acres (nearly one-half a square mile) above Washington Street cannot, in such rains as we have had and are liable to have every few years, be drained by a sewer two feet by three feet, nor by a brook like Town Brook, without overflowing its banks. It is as impossible as it was in 1878 for the Westfield River with its drainage area of 350 square miles to discharge its 53,000 cubic feet of water per second by its river channel without overflowing its banks. To prevent such an overflow the people of Westfield have enlarged the opening at this dam and increased the area of the river channel by building a long and high dike. At Town Brook the same principles must be employed by a different method. The sewer must be made larger, be placed at a lower level and discharged farther down the valley.

A thirty-inch pipe with lead joints could be put in place of the stoned brook through the premises of the Boarding Hall, and the Normal School be drained down School Street to the brook for about half the cost of the sewer proposed by the bill in School Street, and the buildings be as well provided as with that sewer; but neither plan will in the opinion of this Board give adequate and permanent relief. Such relief can be obtained by building a sewer four feet in diameter from where the brook first crosses School Street, west from the Boarding Hall, at a lower level, in which water will have its surface in the different stages, three feet lower than at present. This sewer should be continued down School Street to Elm Street, across Elm and down Main Street to the brook at the Riding Park. Here the sewage and brook water could be turned into Town Brook for the present, but if the water now coming from the canal be cut off, or if, in future, a large amount of sewage be brought down this main sewer in Main Street, it would be necessary then to have at the Riding Park an overfall to discharge storm water directly into Town Brook and continue a smaller sewer, about two feet in diameter, large enough to convey the ordinary sewage down Main Street to the river.

The town of Westfield had an investigation made fourteen years ago and a plan proposed for main sewers in Elm Street and in Main Street. The School Street district by that plan was to drain through the northern part of Elm Street to the river a little below the dam; but there is to this plan this serious objection, which has been brought to notice since the plan was proposed.

The water below the dam, near the outlet then proposed, stood in the great freshet of 1878 at the height of 87.8 feet, and should such a freshet again come the water here would flow back through the sewer into the cellars of a large section of the town, including those of School Street; but at the outlet now proposed near the Riding Park the water of the great freshet stood at the height of 82.7 feet or five feet lower than below the dam, and would consequently flow back to so much less height in cellars; and farther, the increased fall in the shorter distance enables this main sewer to be much smaller than an equally efficient one would be, discharging near the dam.

The engineer of the Board has made an estimate of the cost of such a sewer, which is upon a more liberal basis than the estimates made for the town fourteen years ago and is intended to cover fully all that it would cost to build the sewer at this time, provided no ledge be encountered. This estimate for the sewer four feet in diameter, with its manholes and entrances from where the Town Brook first reaches School Street west of the Boarding Hall to the Town Brook at the Riding Park, amounts to $32,000.

It is the opinion of the Board that such a sewer, shown upon the accompanying plans, should be built by the town of Westfield for the preservation of the health of its residents; and it would in the judgment of the Board be much better for the State to pay the town a liberal assessment towards the building of such a sewer with a branch along Washington Street to the Boarding Hall than for the State to spend the amount proposed in accordance with Bill No. 195, with the inevitable result of neither adequate nor permanent relief. The principal of the school very properly objects to delay in removing the brook from under the Boarding Hall, on account of injury to the inmates and the knowledge of probable injury deterring others from coming to the school. This may be overcome during the necessary time of construction of the sewer by leaving two cellar windows open and from an opposite quarter of the cellar, putting up a wooden flue 18 inches square against the outside of the house, connecting it freely with the upper air in the cellar and producing in it an artificial draught by means of a fan or by a group of burning gas jets sufficient to change the air frequently in the whole cellar.

Westborough Lunatic Hospital. — On the 8th of April the trustees of the hospital requested the Board, among other things, to examine the system of sewage disposal at the hospital and recommend a proper disposal of the sewage.

In a communication to the trustees dated May 9th, treating principally of the condition of the buildings, and advice in regard to them, the Board made the following statement in regard to disposal of their sewage: — *

The present method of disposal of sewage after leaving the hospital is to convey it across the main road to the orchard and let it run on the surface down the hill in the watershed of the Sudbury River, where it forms a small contribution to the water supply of the city of Boston. This method of disposal cannot, of course, be allowed to continue.

There is in this field perhaps fifteen acres, so situated that the sewage could be applied to it advantageously, and under proper management this could be allowed to be done during the months of rapid growth of the crops; but during six months of the year, at least, the sewage should be withheld from this area and taken in an iron pipe to a tract of land over the brook running from Chauncy Pond to Little Chauncy Pond, the drainage from which land is not used for a water supply.

The details of the arrangement of irrigating ditches on these two tracts can be decided after surveys are made giving contour lines at every foot in height, and locating trees and other obstacles to ditching to be avoided. The tract of land over the brook, owned by the hospital, does not appear from an examination to have so many natural advantages for purifying sewage as the twenty-eight acre tract next beyond, which we were told could be bought for a moderate price; and the choice would be determined by the more detailed examination of your engineer designing the arrangement of your irrigation field.

In October, 1887, the trustees of the hospital, through their engineer, submitted a plan proposing a subsoil distribution of the sewage upon a tract of land on the side hill, north of the hospital and outside of the watershed of Sudbury River, so that the effluent would not run into any water used for a domestic supply.

The engineer of the trustees appeared before a committee of the Board Nov. 3, 1887, and explained the nature of the ground upon which he proposed to dispose of the sewage

* The remainder of the letter relative to other sanitary conditions at the Hospital may be found in the General Report. (Public Institutions.)

of the hospital and the general features of the plan. From his account the material proved, by trial pits, to be so much better adapted to the filtration of sewage than inspection of its surface promised, that the Board advised the trustees that it saw no reason to doubt that the sewage of the hospital can be disposed of upon that tract without risk to the health of its inmates or to the public. The details of the method of distribution were not submitted, and the Board consequently expressed no opinion upon the subject.

Clinton. — The Board of Road Commissioners submitted a plan for the sewerage of the town to this Board for advice. It was proposed, generally, to take storm water and sewage together in the same sewers to an intercepting sewer in the valley of Coachlace Brook. This sewer was intended to carry but little more than the dry weather flow of sewage, overflows being provided for the discharge of all excess during storms. The plan provided for carrying the sewage to the bank of the south branch of the Nashua River, but left the question of its final disposal in abeyance. After careful examination of the subject by its engineers, and giving a hearing to all interested, the Board gave the following advice: —

The State Board of Health has by its engineers examined the question presented by the town of Clinton, and advises that the sewage of the town be separated from its storm water, and that the sewage be purified either by intermittent filtration upon land, or by chemical precipitation, or by a combination of the two processes, before being turned into the river.

At the height proposed for the outlet of the main sewer, the sewage for nearly the whole of the present town can be conveyed without pumping to land upon which it may be purified by intermittent filtration; and if the town grows to such an extent that this area becomes insufficient, it can still be used for filtering the night sewage, and the day sewage can be pumped to higher land near, which appears well adapted for the purpose. The height of the outlet would also admit of clarification of the sewage by chemical precipitation.

The town should have the matter of the purification of its sewage carefully examined, and plans therefor, by the best method, prepared by an engineer competent to do such work.

Any data which the chief engineer of the Board may have, which will be of service to the town in such investigation will be at your disposal.

Brockton. — The question of the disposal of the sewage of this city was brought before the Board in February, 1887, while the petition of the city with reference to the same subject was pending in the Legislature. A bill having been there framed, which, if enacted, required subsequent action by this Board before the scheme of sewage disposal contemplated could be carried out, the city authorities did not desire further action at that time.

In July, 1887, no final action having been taken by the Legislature, the joint standing committee on sewerage and drainage of the city of Brockton gave further notice to this Board of their intention to introduce a system of sewerage, and submitted outlines of proposed plans, and asked the Board to consult with and advise them as to the best practicable method of disposing of their sewage. The Board have by themselves and by their engineers, with the assistance of the engineers employed by the city, carefully investigated the different plans which have been proposed, and on Oct. 31, 1887, they gave a hearing at Brockton to all parties interested. The Board to the present time has made only the preliminary report given below, the more detailed report being delayed that the Board might be guided in its advice by the experiments on the disposal of sewage now being carried on by them at the Lawrence Experimental Station.

In response to an application from the city of Brockton to the State Board of Health for advice as to the best practicable method of disposing of the sewage of Brockton, the Board will in future make a more detailed report, but for your immediate use state the following conclusions: that the method of purification by intermittent filtration upon land is best adapted to your circumstances, and that the muster field area, partly in Brockton, partly in Easton and partly in West Bridgewater, is the best adapted for a filtration area for the purification of such sewage, affording abundant area for the future growth of the city.

The Board also finds that the part of this area within the city of Brockton, together with other land near to, and easterly therefrom, which is not so favorable for the same purpose, forms an area within the limits of the city which for several years will be adequate for the purification of the sewage of Brockton.

SOUTHBRIDGE. — The special committee on sewerage of the town of Southbridge, in July, submitted plans for the disposal of the sewage from a portion of the town, in connection with the improvement of the channel of a polluted brook passing through the thickly settled part of the main village. After the matter had been investigated and a hearing had been given to those interested at the rooms of the Board, the following reply was made: —

The Board of Health is not prepared to advise the town of Southbridge to dispose of its sewage in the way proposed by the plans presented. It may not be many years before the town will be required to purify its sewage before discharging it into the river, and the Board advises that before adopting any plan to relieve a locality, a study should be made of a means of conveying the sewage proper of the whole town, separate from storm water or ground water, to a place where it can be pumped to a filtering area and be purified before being turned into the river. Such study and plans being made, it will then be for the Board to decide whether the sewage may temporarily be turned into the river.

By proceeding in this way the Board sees that much expense is likely to be saved by the town in redesigning and rebuilding works unsuited to the work to be required of them.

Such information as may have been obtained by the State Board of Health upon the subject of sewage disposal in general, and with special reference to the conditions existing at Southbridge, will be placed at the disposal of the authorities of your town at the office of the Board.

ATHOL. — The sewerage committee of Athol, Aug. 29, 1887, submitted plans for the sewerage of the town, which proposed the discharge of the sewage into Miller's River, below the lower village, and asked this Board as to their right to so discharge it. The Board replied as follows: —

So long as the river is used as a supply for drinking water at Orange, Athol is, by chapter 80, section 96 of the Public Statutes, prohibited from discharging sewage into the river. The sewage may be purified by filtration through land, so that the effluent may be turned into the river. From an examination made by the engineer of the Board there appears to be land near the Fitchburg railroad, about one and a quarter miles below the proposed outlet, to which the sewage may be pumped, that is suitable for filtration purposes, and it is possible that other suitable area may be found to which it may be conveyed by gravity. The Board advises the town of Athol to have examination made by a competent engineer to determine the most economical method of disposal upon a suitable filtration area, for which purpose the engineer of the Board will give the engineer of the town any data in the possession of the Board that may be of service.

Sherborn Reformatory Prison for Women. — The Commissioners of Prisons, Oct. 10, 1887, asked the advice of this Board in regard to supplementing the present sewage-disposal area by the addition of some land, easterly and across the road from the prison; also, whether the pipe, conveying sewage from the present sewage-tanks to this land, could be carried under the basement of one portion of the building without detriment to the health of the inmates.

The Board, in their reply, suggested some modifications of the plan proposed, and that the pipe passing under the building, and for not less than twelve feet outside of it, should be of cast-iron of the kind used for water-supply in cities, to be connected with tight lead joints. The reply ended with the advice that in the opinion of the Board a pipe sewer constructed of iron as above described, below the basement of the prison building, would not injure the health of the occupants of the prison.

They do not consider the proposed irrigation field east of the prison essential to the general plan of sewage disposal; and they are not prepared to say that the profit from the use of sewage irrigation, as an assistance to the farming operations of the establishment, would yield fair return upon the money thus spent.

Waltham. — The Sewerage and Drainage Commissioners of Waltham, in submitting their scheme for sewage disposal, make the following statement to this Board: —

The Sewerage and Drainage Commissioners of the city of Waltham were ordered by the city council last year to report a system of sewage disposal for our city.

We reported in favor of the system recommended by the State Commissioners, namely: the building of a trunk line of sewer down the valley of Charles River to Boston; to be constructed and maintained by the several cities and towns using it.

Since the action of the Legislature last winter, postponing action on the State Commissioners' report, we have been considering other methods of disposal, and particularly the system of *clarification by the use of precipitants*, and then discharging the effluent into Charles River, and it is with reference to this method of disposal that your advice is particularly desired.

After giving a hearing to the town, the Board sent the following: —

The Board is not prepared to advise the city of Waltham to adopt the plan proposed: to clarify the sewage by chemical precipitation, and discharge the effluent into the Charles River. The general subject of the drainage of the Mystic valley, and so much of the Charles River valley as may be drained with it, has been submitted to this Board by the General Court with instructions to report, one year from this time. Until this examination is completed, the Board will not be in condition to make definite recommendations; but the Board, as at present advised, sees no solution of the question of the sewage disposal of the city of Waltham so satisfactory as some method of conveying it to the deep sea at Moon Island, in conjunction with the city of Newton, and the town of Brookline and the Brighton District of Boston.

Pollution of Inland Waters.

Arlington. — The selectmen and Board of Health of the town of Arlington, on the 14th of February, 1887, presented a communication to this Board representing that Alewife Brook, forming the boundary line between Cambridge and Arlington, received a large quantity of sewage from three Cambridge sewers, and much offensive matter from the slaughter-house of Niles Brothers; that the waters of said brook are at all times contaminated and polluted, and that they constantly endanger and imperil the public health.

These authorities of the town, therefore, requested this Board to take such action in the premises as may be author ized by law to prevent the pollution of the waters of said brook.

A hearing was given March 8, 1887, to the Arlington authorities and other parties interested.

On the 9th of July, 1887, a second communication was received from these same authorities requesting this Board to cause examinations to be made of the waters of Alewife Brook, and of the Lower Mystic Lake, for the purpose of ascertaining whether the same are in a condition likely to impair the interests of the public or imperil the public health. In addition to this request the communication contained substantially the same representation and request as the first one.

The Board caused examination to be made in July and August with the result that they found Alewife Brook polluted to such an extent that it has ceased to be a brook and has become a sewer, and below the entrance of the drain from Niles' slaughter house is much more offensive than ordinary city sewers. Its condition improves somewhat before reaching Mystic River.

The public health requires that such an open sewer should not exist, and the means of relieving the public of this nuisance are a part of the problem of disposal of the Mystic River sewage, which the Legislature has referred to this Board and which is now being actively considered.

On the days when the lower Mystic Lake was visited there was no noticeable odor except in the immediate vicinity of the place where the discharge from the Mystic Valley sewer enters the pond. Chemical examinations, however, show that the waters are polluted, as may be seen by the following analysis of water taken from the surface in the middle of the upper half of the lake, on July 27, 1887, expressed in parts in 100,000 : —

Total residue,	241.50
Loss of residue on ignition,	32.40
Fixed residue,	209.10
Free ammonia,	0.0578
Albuminoid ammonia,	0.0506
Chlorine,	127.0
Nitrogen as nitrates and nitrites	Present

PALMER. — People living along Graves Brook in this town made complaint to the Board that the waters of the brook had become polluted by the filth coming from a carpet mill, including both the manufacturing refuse or drainage and the washings from privy vaults, to such an extent as to make the waters foul and offensive, and to imperil the public health. The circumstances were examined and the following response made on December 7 : —

Section 96 of chapter 80 of the Public Statutes provides that "no human excrement shall be discharged into any stream used as a source of water supply by a town within twenty miles above the point where such supply is taken, or into any feeders of such stream within such twenty miles."

Water being used from the river at Chicopee Falls for domestic purposes within twenty miles from the carpet mill at Palmer, this mill and all others in the vicinity are prohibited from discharging their privies into the stream. As to the further discharge from the carpet mill the State Board of Health does not see that in the case as stated by you they have authority to interfere.

DISPOSAL OF MANUFACTURING DRAINAGE OR REFUSE.

NORTHAMPTON. — On the 3d of December, 1887, an application was made to this Board for advice with reference to the disposal of the drainage from proposed soap works to be built in Northampton. The Board caused examinations of the locality to be made by its secretary and appointed a time for a public hearing, when the application was withdrawn on account of the failure to procure the desired land for the works.

II.

The following observations pertain to the operations of the Board referred to in the second department of work.*

The Board of Health has at various times called attention to the limitations of the methods hitherto practised for determining the character of the substances present in water, which may have an injurious effect upon human health.

It was therefore decided to call to the assistance of the Board some analytical chemist of the highest repute, who should be directed not only to repeat such examinations as have heretofore from time to time been made, but also to again critically examine the successive steps of such examinations with a view to their possible improvement and extension.

We believe that at the end of a year's work we can point to improved methods of analysis, and that we shall then be in condition to give a more exact interpretation of results.

Prof. T. M. Drown of the Massachusetts Institute of Technology has had charge of the chemical analyses. Mrs. R. H. Richards has had the immediate oversight of the laboratory staff, consisting of Messrs. A. H. Gill, Henry Martin, H. A. Richardson and Miss Isabel F. Hyams. Regular work was begun in June, 1887, and there have been examined 1,509 samples of water. In accordance with the general plan, as above stated, a great deal of work has been done in studying the changes which waters undergo in different conditions, and in perfecting analytical processes in the line of greater accuracy and rapidity.

We have thought it advisable to withhold a general discussion of the analyses already made until we have in our possession observations extending through all the seasons of the year.

The chemical examinations of the water supplies have been accompanied so far as possible by a study of the animal and vegetable life always present to a greater or less degree in surface waters.

Mr. G. H. Parker, S.B., assistant in Zoölogy in Harvard

* See page 2.

University, has had charge of the examinations of waters with reference to the forms of vegetable and animal life which are either evident to the naked eye or which can be studied with the lower powers of the microscope. To E. K. Dunham, M.D., was assigned the investigation of the bacteria and kindred forms of vegetable life, which can only be studied with the higher powers of the microscope, and by various elaborate methods of cultivation, requiring much time and great technical skill.

Mr. Parker began his work in July. Dr. Dunham entered upon his investigations in October. It is too early, therefore, to attempt to draw many very definite conclusions from their observations in their respective fields of inquiry.

The details of a plan for procuring samples of water from the various supplies under consideration, so accurately defined as to permit of comparison with samples taken from the same sources throughout the year or in any succeeding year, have been carefully prepared by the chief engineer of the Board, F. P. Stearns, C. E.

Preliminary to this work all the statistical information which could be obtained was brought together and so arranged that all the recorded facts concerning any public water supply were made available. We can therefore compare with more confidence than ever before our successive observations of the water supplies of the State.

All the important details relating to this subject will be found in the report of Mr. Stearns hereto appended, together with a very instructive discussion of some of the results obtained.

It will be seen that municipalties representing eighty-two per cent. of the whole population of the State are provided with public water supplies, — a sufficient argument for treating this question with a consideration due to one of our most important sanitary problems, and with the certainty, moreover, that the difficultes of the situation will increase from day to day. Some observations upon the composition of water in filter galleries by the side of streams and ponds will also be found in this Appendix, to which attention is also called. They have great practical value in demonstrating some of the advantages of this method of collecting potable waters.

As only a limited number of water supplies could be examined by Mr. Parker and Dr. Dunham, it was thought wise to begin with the largest and most important supplies, first on account of the great number of people dependent upon them, and secondly, because all their physical conditions were much better known, and because more information could be had without expense to the State. From time to time other water supplies have been examined in this exhaustive manner, as occasion has seemed to require.

Three classes of plants are found in our ponds and reservoirs. First, those which are fixed in the basins, such as the common pond weeds and a few filamentous algæ. Second, those which are suspended in the water, but do not readily decompose, including the common green algæ (*desmids*, *diatoms*, etc.) and duck-weeds. Third, those which are suspended in the water and readily decompose, the blue-green algæ (*Cœlosphœrium*, *Anabœna*, and *Clathrocystis*).

Plants firmly fixed in streams and basins are harmful mainly in affording a lodging-place for the development of plants belonging to the groups two and three above noted. In basins having much fluctuation of level, plants of the first group may injure the water by their death and consequent decay.

The floating plants of the second group are injurious, since, after a long carriage through a closed conduit or in continued hot weather, they die and decompose. In Boston water, taken from a tap, they are usually dead; in Cambridge they are usually alive in the water taken in the same way, and offend only the sense of sight.

The members of the third class multiply very rapidly, and secrete a jelly, which, together with the plant, readily undergoes decomposition. These plants usually decay in the basins, and are represented in the water drawn from the taps only by a few fragments.

Of animals, two classes may be mentioned: the fixed or sessile forms, and the free swimming. Of the latter the *entomostraca* are the only troublesome forms, and these mainly in the hot weather, when the rate of reproduction is very high. Of the sessile animals two are noteworthy, the fresh water sponge and the polyzoa. The latter usually encrust the gates and open ends of pipes. One gelatinous form lives in the ponds, — sometimes free, sometimes attached.

The comparatively small number of the polyzoa and their hardiness render them generally less important than some of the other organisms. The sponges are undoubtedly the most troublesome of the animals found in water supplies. They seem to have established themselves in the service-pipes of the Boston and Charlestown systems, but are not found in the Cambridge system. They readily decompose and strongly taint the water. They are now conspicuously absent in the sources of Boston's water supply.

Some of the lines upon which relief from the nuisance occasioned by these organisms may be sought are the following: Fixed plants can be cleared from ponds by the usual methods of raking. Improvements of the ponds by deepening and removing the loam will probably do much to check the growth of plants in groups two and three.

In Mr. Parker's preliminary report, which is printed in the Appendix,* will be found some observations upon the changes undergone by water from one locality, under the different conditions of storage in a filter gallery, in an open and in a covered reservoir. These observations have a great practical value, and demonstrate the value of covered reservoirs as a protection against the vegetable life, which seems to be the ordinary source of the disagreeable tastes and smells so common in our ponds and reservoirs.

Four rivers in the State have been systematically examined. These are the Taunton, the Blackstone, the Charles, and the Merrimack.

In the study of composition of river waters and the changes which they undergo in their progress, we must, in addition to the chemical determinations, bring into our consideration the geology and surface topography of the region through which the rivers flow. Wooded and swampy lands will give to their waters, with sluggish flow, high color

* See Appendix A.

and much soluble vegetable matters. Barren and rocky districts have rapid streams with little organic impurity and more or less mineral matter, according to the character of the rocks over which they flow.

Deep mountain lakes furnish water of high purity, without odor or color, and the waters of shallow lakes and ponds in low rolling country are generally colored from dissolved vegetable matters, and often have a distinct odor from aquatic growths of vegetable or animal origin.

Any investigation, therefore, into the pollution of streams by the drainage of human habitations or by manufacturing refuse, presupposes the study of the streams themselves, and the nature of their mineral and organic contents before they reach the point of pollution from sewage or similar drainage.

It is well to bear in mind that, although the admission of sewage into streams constitutes the principal and dangerous pollution, natural waters, far removed from human settlement, may be impure and repellent by reason of the products of vegetable and animal growth and decay. Because a stream is dark colored or is distasteful, and contains organic matter and products of putrefactive change, we must not take it for granted that it is contaminated by human refuse, or that it is dangerous in containing, necessarily, the germs of specific disease.

One chemical analysis of the water from a stream will not tell us (except in extreme cases) whether the stream is or is not contaminated dangerously with sewage. Indeed, many analyses of the water taken at random at different seasons may often fail to give us this information. We need to know what is the character of the water under normal conditions of rainfall, and also what it is in dry seasons, and when the water is unusually high. When a stream is swollen after heavy rains the water is turbid from suspended earthy matters and matters of organic origin washed down from the banks of the stream. An analysis made under these conditions will give a very different result from what would be obtained during summer heat and drought. Yet the knowledge of the character of the water under both conditions is a matter of importance, in the study of the changes which a stream undergoes as it flows through a populous and manufacturing district.

Further, the degree of the pollution of a stream will obviously depend on the relation between the volume of the water flowing and the amount of contaminating material which enters it. The fouling of small streams by an amount of drainage which a large river would absorb without noticeable effect, is a matter of common observation. Nevertheless, when it concerns the matter of a supply of water for drinking purposes it is of the first importance to keep a jealous watch over the effect of an increasing volume of drainage entering rivers even of large size.

In the chemical analyses of the waters of the rivers (as well as the water supplies of the State in general) those substances have been determined which experience has shown to be the most important in influencing the character of water when used for domestic purposes. Briefly expressed, the scheme of analysis is as follows: The water is inspected for turbidity and sediment. The odor at ordinary temperatures, and at a point near boiling, is noted. Its color is recorded on a scale formed by adding the so-called Nessler reagent to varying amounts of ammonium chloride. This scale is the same as that used in the determination of free and albuminoid ammonia. Color 1 is a distinct yellowish brown when seen in a depth of five or six inches; 2 is a decided yellowish brown. On this scale Cochituate water as drawn from a faucet is on an average about 0.35. The "total solids" express the amount of both organic and mineral matters which the water contains. The "loss on ignition" represents in most of the surface waters very closely the organic matters, and the "fixed solids" those of mineral origin. And here it should be said that it has been the usual practice in carrying out these analyses to include the sediment and suspended matters in the determinations, except in those cases where the amount of undissolved matters is excessive by reason of heavy rains or other causes. In such cases the determination has been made on both the unfiltered and filtered sample.

"Free ammonia" is one of the products of the decay of organic nitrogenous matter, either vegetable or animal, and "albuminoid ammonia" represents the amount of nitrogenous matter which is capable of giving ammonia in the process of decay. The "nitrogen in the form of nitrates" expresses the completion of changes which go on in nitrogenous matters in their progress from the organized to the inorganic condition.

Chlorine is generally present in water as chloride of sodium or common salt (one part of chlorine being equivalent to 1.65 parts of common salt). It may come from the soils and rocks over and through which the water passes, and from proximity to the sea, and it may also come from the waste products of human life and manufacture. It is this latter origin that gives it its great significance in water analyses as a possible indication of sewage, in which it is always present in considerable amount.

In the following table of analyses of four of the rivers of the State these determinations have been arranged in two groups, in order to bring together the determinations which are most closely related to one another. Thus, we have a table of *Organic Contents*, in which will be found the nitrogen in the form of free ammonia, in the form of albuminoid ammonia, and in the form of nitrates. With these is given the color of the water (on the scale mentioned above), since a very close correspondence has been made out between the depth of the color (which represents the vegetable organic matter in solution) and the amount of albuminoid ammonia.

In the other table of *Mineral Contents* the fixed solids express the amount of the mineral matters present, and the chlorine the contents of salt. The loss on ignition, as before said, is approximately the total amount of organic matter present, irrespective of its origin and character. The turbidity is given in this table, since it bears a close relation to the amount of solids determined by analysis. The chemical results embrace a period of seven months, from June to December.

The study of these tables is interesting and profitable, but as they cover only a part of the year any conclusions drawn from their study in their present form may have to be modified as the work progresses. Moreover, the past summer was one of unusual rainfall, and the waters of this period cannot be considered as normal.

The collection of the samples of water was so planned that the waters of any one river should be taken from the various stations as near as possible on the same day. Even with this precaution to ensure comparable results local rains have at times a disturbing influence. The samples taken from the tributaries of the rivers are given in the same series as the rivers, but they were not as a rule collected at the same time.

The Taunton River.

The Taunton River represents a drainage area of 450 square miles. Within this area the waters of the river and its tributaries have been examined at nine stations, mainly in the eastern portion; but the monthly samples from these points were not always collected on the same day. The analyses have been arranged in three groups. First, the Salisbury Brook above Brockton, which furnishes the water supply of the city, Salisbury Plain River below Brockton, and the Taunton River at Sturtevant's Bridge, Bridgewater, just above its junction with the Nemasket. In the second group are the waters brought in by the Nemasket, namely: Elders Pond, Little Quittacas Pond, Assowompset Pond, the Nemasket at Middleborough, and also at the Old Mill just before it joins the Taunton. In the third group are two stations on the Taunton River, one just below its junction with the Nemasket at Dunbar's Bridge, and the other at the city of Taunton (see Tables Ia and Ib). It would be interesting in studying the character of the waters of this area to know the kind of water brought in by the eastern tributaries, and those draining North Easton and Bridgewater, which flow into the Taunton before its junction with the Nemasket. On comparing the character of the first two groups one is first impressed with the fact that the waters from the north are high colored, and that those from the south, brought in by the Nemasket, have but little color. This high color is accompanied, as usual, with high albuminoid ammonia. The lighter colored waters from the south, with lower amount of albuminoid ammonia, have a

TABLE I. "A."

TAUNTON RIVER AND TRIBUTARIES.

(ORGANIC CONTENTS). PARTS IN 100,000.

NORTHERN TRIBUTARIES.

	SALISBURY BROOK, BROCKTON STORAGE RESERVOIR.					SALISBURY PLAIN RIVER, BROCKTON.					TAUNTON RIVER, ABOVE THE NEMASKET, BRIDGEWATER.			
	Color.	Free Ammonia	Albuminoid Ammonia.	Nitrogen as Nitrates.		Color.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates.		Color.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates.
1887.					Receives drainage of Brockton between the points at which the samples were taken, as indicated in the analyses at the right and left of this space.					Receives many tributaries between these points.				
June, . .	1.2	.0010	.0304	.006		–	–	–	–		–	–	–	–
July, . .	1.2	.0010	.0370	.004		–	–	–	–		1.3	.0036	.0351	.007
August,* .	1.0	.0017	.0858	.003		–	–	–	–		–	–	–	–
September,	0.9	.0009	.0978	.003		–	–	–	–		1.0	.0007	.0342	.007
October, .	0.8	.0068	.0518	.008		1.3	.0320	.0150	.070		1.5	.0014	.0300	.013
November, .	1.0	.0062	.0345	.014		–	–	–	–		1.4	.0021	.0358	.008
December, .	0.8	.0040	.0327	.010		–	–	–	–		1.5	.0034	.0336	.012
Mean, . .	1.0	.0033	.0541	.007		–	–	–	–		1.5	.0022	.0338	.009

* This sample was taken early in September.

SOUTHERN TRIBUTARIES.

	ELDER'S POND, LAKEVILLE.				LITTLE QUITTACAS POND, LAKEVILLE.				ASSOWOMPSET POND, LAKEVILLE.				NEMASKET RIVER, MIDDLEBOROUGH.				NEMASKET RIVER, AT OLD MILL, BRIDGEWATER.			
	Color.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates.	Color.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates.	Color.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates.	Color.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates.	Color.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates.
1887.																				
June, . .	–	–	–	–	–	–	–	–	–	–	–	–	0.6	.0005	.0200	.000	–	–	–	–
July, . .	–	–	–	–	–	–	–	–	–	–	–	–	0.7	.0005	.0214	.000	0.5	.0005	.0193	.000
August, .	–	–	–	–	–	–	–	–	–	–	–	–	0.35	.0002	.0170	.000	–	–	–	–
September,	0.0	.0003	.0130	.003	0.15	.0007	.0170	.007	0.1	.0000	.0154	.003	0.2	.0001	.0184	.000	0.2	.0003	.0142	.013
October, .	–	–	–	–	–	–	–	–	–	–	–	–	0.5	.0004	.0205	.000	0.3	.0004	.0202	.003
November, .	–	–	–	–	–	–	–	–	–	–	–	–	0.1	.0006	.0130	.003	0.55	.0008	.0101	.002
December, .	–	–	–	–	–	–	–	–	–	–	–	–	0.5	.0006	.0210	.002	0.9	.0008	.0214	.008
Mean, . .	–	–	–	–	–	–	–	–	–	–	–	–	0.4	.0003	.0188	.002	0.5	.0006	.0188	.005

RIVER BELOW JUNCTION.

TAUNTON RIVER— AT DUNBAR'S BRIDGE, BRIDGEWATER.				TAUNTON RIVER— AT TAUNTON.				
Color.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates	Color.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates.	
								1887.
2.0	.0032	.0320	.000	1.2	.0034	.0322	.013	June.
–	–	–	–	1.1	.0030	.0265	.013	July.
1.7	.0023	.0340	.003	1.3	.0043	.0271	.007	August.
1.4	.0013	.0241	.007	1.5	.0047	.0302	.007	September.
1.0	.0008	.0216	.007	1.0	.0004	.0212	.008	October.
1.1	.0013	.0285	.010	1.4	.0026	.0286	.010	November.
–	–	–	–	1.5	.0024	.0334	.010	December.
1.4	.0018	.0280	.005	1.3	.0030	.0285	.009	Mean.

TABLE I. "B."

TAUNTON RIVER AND TRIBUTARIES.

(MINERAL CONTENTS). Parts in 100,000.

NORTHERN TRIBUTARIES.

	Salisbury Brook, Brockton Storage Reservoir.						Salisbury Plain River, Brockton.						Taunton River, above the Nemasket, Bridgewater.				
	Turbidity.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.		Turbidity.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.		Turbidity.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.
1887.																	
June, . .	Decided,	4.42	1.57	2.85	.30		–	–	–	–	–		–	–	–	–	–
July, . .	Decided,	4.32	1.70	2.02	.20	Receives Drainage of Brockton.	–	–	–	–	–	Receives many tributaries between these points.	Very slight,	6.55	2.15	4.40	.57
August,* .	Heavy, .	5.80	2.02	2.88	.33		–	–	–	–	–		–	–	–	–	–
September, .	Heavy, .	5.95	2.05	3.00	.30		–	–	–	–	–		Decided,	7.00	2.10	4.90	.69
October, .	Decided,	4.50	2.15	2.35	.37		Heavy, .	10.60	2.90	7.70	1.20		Decided,	6.55	1.60	4.05	.72
November, .	Slight, .	4.45	2.15	2.30	.37		–	–	–	–	–		Decided,	7.50	3.45	4.05	.69
December, .	Decided,	5.15	2.30	2.85	.38		–	–	–	–	–		Decided,	7.45	3.25	4.20	.70
Mean, . .	–	4.05	2.27	2.07	.33		–	–	–	–	–		–	7.01	2.51	4.50	.67

* This sample was taken early in September.

SOUTHERN TRIBUTARIES.

	Elder's Pond, Lakeville.					Little Quittacas Pond, Lakeville.					Assawompset Pond, Lakeville.					Nemasket River, Middleborough.					Nemasket River, at Old Mill, Bridgewater.				
	Turbidity	Total Solids	Loss on Ignition.	Fixed Solids.	Chlorine	Turbidity	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.	Turbidity.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine	Turbidity.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine	Turbidity.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.
1887.																									
June, . .	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	Slight, .	3.47	2.05	1.42	.49	–	–	–	–	–
July, . .	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	None, .	3.60	1.30	2.30	.39	None, .	3.45	1.10	2.35	43
August, .	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	None, .	3.10	1.30	1.80	.48	–	–	–	–	–
September, .	Distinct,	2.50	0.67	1.03	.41	Slight, .	2.97	0.87	2.10	.48	Distinct,	2.05	0.90	2.05	.48	Slight, .	3.27	1.05	2.22	.47	Very slight,	3.70	0.85	2.85	.51
October, .	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	Very slight,	3.75	1.10	2.65	.51	Very slight,	3.90	1.30	2.60	.53
November, .	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	Very slight,	3.40	1.30	2.10	.47	Very slight,	4.20	1.30	2.90	.52
December, .	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	Very slight,	4.45	1.70	2.75	.52	Very slight,	4.90	1.00	3.30	.59
Mean, . .	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	3.58	1.40	2.18	.48	–	4.03	1.23	2.80	.53

RIVER BELOW JUNCTION.

Taunton River – At Dunbar's Bridge, Bridgewater.					Taunton River – At Taunton.					
Turbidity.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.	Turbidity.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.	
										1887.
Very slight,	6.57	3.27	3.30	.42	Slight, .	4.07	1.85	3.12	.48	June.
–	–	–	–	–	Slight, .	5.20	1.55	3.65	.48	July.
Very slight,	6.50	2.87	3.63	.51	Very slight,	5.60	1.32	3.78	.62	August.
Decided,	5.80	1.85	3.05	.60	Slight, .	5.85	1.70	4.15	.59	September.
Slight, .	5.25	1.15	4.10	.65	Slight, .	6.10	1.70	4.40	.72	October.
Very slight,	6.30	2.45	3.85	.72	Slight, .	6.55	3.00	3.65	.73	November.
–	–	–	–	–	Distinct,	6.50	3.00	3.50	.58	December.
–	6.28	2.51	3.77	.58	–	5.84	2.09	3.75	.60	Mean.

very slight effect in reducing the intensity of the color in the northern waters, on account of the much smaller volume of water flowing in the Nemasket.

The Taunton River, after receiving the purer waters of the Nemasket, is but slightly altered in color, and the free and albuminoid ammonia are not much reduced. The waters from the north are also more turbid, and carry more earthy and flocculent sediment than those from the south. To this suspended matter, as well as to the organic matter in solution, much of the albuminoid ammonia is due. Thus the sample for October from the Brockton storage-reservoir, on Salisbury Brook, which gave .0518 parts of albuminoid ammonia, gave only .0282 after simple filtration through paper. The high loss on ignition in this water, nearly one-half of the total solids, points also to a large amount of organic matter. The mineral matters, or fixed solids, increase in the northern tributaries from 2.67 at Salisbury Brook to 4.50 at Sturtevant's Bridge, and the chlorine, which generally increases in the same ratio as the fixed solids, rises from 0.33 to 0.67 parts. In the southern tributaries we have much less solid matter brought in, both organic and mineral. The turbidity and sediment are, as a rule, less, and the fixed solids and loss on ignition are both lower

After the union of the rivers the Taunton, owing to its much greater volume, preserves its general character, but the Nemasket waters have, nevertheless, a noticeable effect in lowering the free and albuminoid ammonia and the fixed mineral contents. In the further progress of the river to the city of Taunton, it remains substantially constant in composition ; but the effect of the drainage of a populous region is shown in a decided tendency to an increase of the free ammonia.

The Charles River.

The Charles River has been examined regularly at five points, — at South Natick, West Roxbury, Newton Upper Falls, Waltham, and Watertown. There are, also, one analysis of the river water at Milford, three of Rosemary Brook, which joins the river below Newton Upper Falls, and five of Stony Brook, which flows into the river above

Waltham. If we compare the averages of the two end points in this series (see Table IIa and IIb), namely, the river at South Natick and at Watertown, the contrast is striking. The free ammonia is increased ten-fold, the nitrogen as nitrates three-fold, the fixed solids rise from 3.83 to 5.54 parts, the chlorine from 0.43 to 0.69 parts, and there is a decrease in color in the proportion of 84 to 57. In so far as these figures express in a general way the tendency to progressive pollution they convey important information, but they are misleading if they give the idea that the river at Watertown always bears this relation to the river at South Natick. If we compare the analyses of the waters from these two stations in July, we find the composition nearly identical as regards organic contents; but in November, the free ammonia and nitrates are very much higher in the river at Watertown. A single random analysis may sometimes tell us a good deal about a water, but it may lead to serious error if we attempt to get from it more information than the actual figures tell us of the composition of the one sample, taken under certain conditions and at a certain time. The danger of error decreases with the number of analyses and the length of time covered by the investigation, but it is not entirely eliminated until we are thoroughly acquainted with causes of accidental changes in a stream, as well as with those which are regular and normal.

The high albuminoid ammonia of the water at South Natick is normal if we take into consideration the general average high color of this water, and the low free ammonia associated with it points to the vegetable nature of this impurity. At Watertown the water is generally of lower color with a tendency to high free ammonia, conditions which point to contamination by drainage.

The mineral contents of surface waters are not, as a rule, subject to such irregular and fitful changes as the organic contents. Thus, in the Charles River the chlorine increases steadily, almost without break, from Milford to Watertown. The changes show great regularity both in the waters of each station when compared with themselves, and also from station to station as the stream flows onward. In general,

TABLE II. "A."

CHARLES RIVER.

(ORGANIC CONTENTS). PARTS IN 100,000.

	At Milford.				At South Natick.				At West Roxbury. Brookline Supply.				At Newton Upper Falls.			
	Color.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates.	Color.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates.	Color.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates.	Color.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates.
1887.																
June,	–	–	–	–	–	–	–	–	1.2	.0042	.0423	.000	1.0	.0020	.0306	.000
July,	–	–	–	–	0.9	.0010	.0256	.000	0.9	.0011	.0251	.000	0.7	.0004	.0202	.000
August,	–	–	–	–	1.4	.0012	.0302	.007	1.1	.0002	.0274	.007	1.0	.0008	.0249	.000
September,	–	–	–	–	0.75	.0003	.0348	.003	0.8	.0010	.0322	.007	0.7	.0011	.0307	.007
October,	–	–	–	–	0.5	.0005	.0225	.010	0.4	.0005	.0202	.013	0.4	.0000	.0208	.005
November,	–	–	–	–	0.6	.0000	.0267	.008	0.6	.0008	.0218	.005	0.6	.0004	.0242	.008
December,	1.1	.0035	.0269	.008	0.9	.0020	.0276	.010	0.7	.0000	.0278	.018	0.7	.0004	.0240	.018
Mean,	–	–	–	–	0.84	.0008	.0284	.006	0.8	.0012	.0281	.008	0.7	.0007	.0263	.005

	Tributaries. Rosemary Brook, Wellesley.				Tributaries. Stony Brook, Waltham. Cambridge Supply.				At Waltham.				At Watertown.			
	Color.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates.	Color.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates.	Color.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates.	Color.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates.
1887.																
June,	–	–	–	–	1.3	.0060	.0552	.000	1.2	.0044	.0440	.000	–	–	–	–
July,	–	–	–	–	0.7	.0006	.0297	.003	0.6	.0034	.0249	.000	0.9	.0000	.0307	.003
August,	–	–	–	–	1.0	.0024	.0260	.000	0.7	.0052	.0270	.003	0.6	.0055	.0237	.035
September,	–	–	–	–	0.7	.0001	.0366	.003	0.55	.0037	.0271	.007	0.6	.0000	.0291	.013
October,	0.3	.0008	.0176	.019	0.7	.0074	.0340	.007	0.5	.0010	.0241	.007	0.45	.0056	.0249	.026
November,	0.1	.0005	.0131	.030	0.45	.0071	.0262	.008	0.5	.0010	.0192	.000	0.3	.0305	.0255	.040
December,	0.3	.0018	.0103	.025	–	–	–	–	0.5	.0026	.0272	.020	–	–	–	–
Mean,	0.23	.0010	.0160	.024	0.61	.0040	.0347	.004	0.65	.0029	.0276	.007	0.57	.0080	.0268	.023

TABLE II. "B."

CHARLES RIVER.

(MINERAL CONTENTS). PARTS IN 100,000.

	At Milford.					At South Natick.					At West Roxbury. Brookline Supply.					At Newton Upper Falls.				
	Turbidity.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.	Turbidity.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.	Turbidity.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.	Turbidity.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.
1887.																				
June,	–	–	–	–	–	–	–	–	–	–	Very slight,	5.15	2.27	2.88	.44	Very slight,	5.05	1.02	4.03	.30
July,	–	–	–	–	–	Very slight,	5.10	1.50	3.30	.35	Very slight,	4.92	1.77	3.15	.38	Slight,	5.07	1.62	3.45	.38
August,	–	–	–	–	–	None,	5.05	1.97	3.08	.35	Very slight,	5.85	1.90	3.95	.32	Very slight,	5.60	1.80	3.80	.38
September,	–	–	–	–	–	Distinct,	5.60	1.60	4.00	.44	Slight,	5.07	1.40	4.18	.30	Slight,	5.62	1.40	4.22	.43
October,	–	–	–	–	–	Very slight,	4.90	1.10	3.80	.47	Very slight,	4.80	1.15	3.65	.53	Very slight,	5.30	1.25	4.05	.50
November,	–	–	–	–	–	Slight,	5.30	1.55	3.75	.54	Slight,	5.85	1.15	4.70	.50	Slight,	5.65	0.95	4.70	.62
December,	Very slight,	4.50	2.10	2.40	.30	Slight,	5.85	1.70	4.15	.45	Distinct,	6.20	1.05	4.25	.52	Slight,	6.20	1.80	4.40	.56
Mean,	–	–	–	–	–	–	5.45	1.62	3.83	.43	–	5.40	1.67	3.82	.45	–	5.63	1.53	4.09	.48

	Rosemary Brook, Wellesley.					Stony Brook, Waltham. Cambridge Supply.					At Waltham.					At Watertown.				
	Turbidity.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.	Turbidity.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.	Turbidity.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.	Turbidity.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.
1887.																				
June,	–	–	–	–	–	Very slight,	6.72	3.25	3.47	.45	–	6.07	2.32	3.75	.40	–	–	–	–	–
July,	–	–	–	–	–	Distinct,	6.25	1.72	4.53	.37	Very slight,	5.50	1.80	3.70	.40	Distinct,	6.75	2.00	4.75	.60
August,	–	–	–	–	–	Very slight,	5.92	1.80	4.12	.45	Distinct,	6.20	1.37	4.83	.38	Slight,	6.97	1.30	5.67	.59
September,	–	–	–	–	–	Decided,	6.30	1.12	5.18	.42	Slight,	6.27	1.40	4.87	.50	Distinct,	6.90	1.15	5.75	.62
October,	Distinct earthy,	5.40	0.80	4.60	.64	Distinct,	6.05	1.25	4.80	.43	Slight,	5.90	1.10	4.80	.57	Distinct,	7.15	1.40	5.75	.75
November,	Very slight,	5.35	0.95	4.40	.65	Slight,	6.00	1.75	4.25	.48	Decided,	6.20	1.75	4.45	.60	Distinct,	7.80	2.00	5.80	.88
December,	Slight,	5.85	1.25	4.60	.67	–	–	–	–	–	Distinct,	6.85	2.10	4.75	.60	–	–	–	–	–
Mean,	–	5.53	1.00	4.53	.65	–	6.20	1.81	4.39	.43	–	6.14	1.69	4.45	.51	–	7.11	1.57	5.54	.69

TABLE III. "A."

BLACKSTONE RIVER.

(ORGANIC CONTENTS). Parts in 100,000.

	Holden Storage Reservoir.				Leicester Storage Reservoir.					Worcester, 1 Mile below Outlet of Worcester Sewer.				Uxbridge, Diluted by Lake Quinsigamond and other Tributaries.				Millville.			
	Color.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates.	Color.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates.		Color.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates.	Color.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates.	Color.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates.
1887.																					
June, . .	0.1	.0002	.0148	.013	0.10	.0001	.0131	.000	Receives many tributaries and the sewage of Worcester.	1.0	.0020	.3620	–	0.3	.1140	.6361	.019	0.2	.0565	.0232	.006
July, . .	–	–	–	–	–	–	–	–		0.2	.3670	.1340	–	0.4	.1320	.1530	.052	0.5	.0396	.0230	.013
August, .	0.0	.0019	.0220	.003	0.40	.0036	.0189	.003		2.0	.2000	.1280	.010	0.45	.0264	.0270	.005	0.4	.0050	.0243	.033
September, .	0.2	.0000	.0188	.006	0.15	.0014	.0184	.003		0.1	.2640	.1200	.013	0.3	.0492	.0216	.039	0.16	.0128	.0212	.033
October, .	0.4	.0000	.0236	.003	0.35	.0092	.0224	.007		1.3	.0884	.0376	.010	0.5	.1672	.0256	.026	0.3	.0770	.0232	.026
November, .	0.3	.0012	.0218	.000	0.50	.0112	.0238	.006		*	.5300	.2630	.025	0.4	.1888	.0102	.015	0.2	.0896	.0172	.015
December, .	0.2	.0006	.0170	.002	0.35	.0088	.0105	.007		0.9	.2180	.0600	.025	0.7	.1260	.0380	.025	0.5	.0636	.0312	.018
Mean, . .	0.3	.0007	.0197	.004	0.31	.0057	.0194	.004		0.92	.2471	.1578	.018	0.44	.1148	.0430	.034	0.34	.0492	.0233	.021

* Colored by Iron.

TABLE III. "B."

BLACKSTONE RIVER.

(MINERAL CONTENTS). Parts in 100,000.

	Holden Storage Reservoir.					Leicester Storage Reservoir.					Worcester, 1 Mile below Outlet of Worcester Sewer.					Uxbridge, Diluted by Lake Quinsigamond and other Tributaries.					Millville.				
	Turbidity.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.	Turbidity.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.	Turbidity.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.	Turbidity.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.	Turbidity.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.
1887.																									
June, . .	Slight, .	2.27	1.07	1.20	.14	Slight, .	2.02	0.87	2.05	.14	Thick and dirty, .	22.90	9.30	13.60	1.47	Decided, .	6.65	1.52	5.13	.77	Slight, .	5.52	1.82	3.70	.53
July, . .	–	–	–	–	–	–	–	–	–	–	Thick and dirty, .	42.00	3.25	38.75	2.12	Distinct, .	7.27	1.27	6.00	.82	Distinct, .	4.80	1.00	3.80	.42
August, .	Distinct, .	3.07	1.62	1.46	.03	Very slight,	3.20	1.30	1.00	.11	Thick and dirty, .	18.50	3.70	14.80	1.24	Distinct, .	7.05	1.65	5.40	.66	Slight, .	5.22	1.07	4.15	.41
September, .	Decided, .	2.50	0.90	1.60	.15	Decided, .	2.90	0.55	2.35	.14	Thick and dirty, .	23.90	7.30	16.60	.93	Distinct, .	7.37	1.40	5.97	.71	Slight, .	5.30	1.35	3.95	.52
October, .	Decided, .	2.65	0.75	1.90	.13	Slight, .	3.25	0.75	2.50	.15	Thick and dirty, .	16.60	6.10	10.50	.90	Distinct, .	7.55	1.35	6.20	.81	Distinct, .	5.50	1.35	4.15	.59
November, .	Decided, .	2.60	0.95	1.65	.15	Distinct, .	3.30	1.20	2.10	.16	Thick and dirty, .	Filt. 34.00	10.20	23.80	1.40	Distinct, .	7.45	1.20	6.25	.90	Distinct, .	5.20	1.10	4.10	.50
December, .	Distinct, .	2.65	0.75	1.90	.15	Slight, .	3.35	1.00	2.35	.17	Thick and dirty, .	16.60	6.30	10.30	1.63	Decided, .	8.15	1.65	6.50	.80	Distinct, .	5.60	1.25	4.35	.53
Mean, . .	–	2.62	1.01	1.62	.13	–	3.15	0.95	2.21	.15	–	24.93	6.60	18.34	1.39	–	7.36	1.43	5.92	.70	–	5.31	1.28	4.03	.51

the months lowest in chlorine throughout the series were July and August, and the highest November and December. If we had only the chlorine determination at South Natick in November and the chlorine at Watertown in August, the contamination of the stream as shown by these figures from South Natick to Watertown would be as 54 to 59 (1 to 1.1), whereas the relation between the two determinations in August shows 39 to 59 (1 to 1.69), and between the two in November as 54 to 80 (1 to 1.63). The evidence of pollution by drainage which we get by the determination of the free and albuminoid ammonia must, in this way, always be confirmed by the evidence furnished by the contents of chlorine; but to be sure of our ground we must know that the conditions under which the samples were taken make the determinations fairly comparable.

The nitrogen in the form of nitrates at Watertown is higher than in the upper waters of the Charles. This shows a complete oxidation of a small portion of the nitrogenous matter, presumably of animal origin, and it affords an additional proof of previous contamination. The process of nitrification is not very active in river waters, and the nitrates do not there assume the same significance as they do in ground waters.

The Blackstone River.

The Blackstone River affords a good instance of intense pollution of a stream by excessive sewage and the waste products of factories, and its partial purification by subsequent dilution. (See Tables IIIa and IIIb.) The head waters of the river, represented by the Holden and Leicester storage reservoirs, are fairly good waters of moderate color, with a marked tendency, in the Leicester reservoir, towards the development of free ammonia, which, however, is not accompanied by high chlorine.

The river about one mile below Worcester, after having received the sewage of the city and the waste liquors from the Washburn & Moen Wire Works, is excessively foul. It is muddy and dirty in appearance, and full of dark flocculent, suspended matter. It has frequently an acid reaction from the pickling liquors. The water at this point may be fairly called sewage.

At Uxbridge the river has received the water from Lake Quinsigamond and other tributaries, and shows in consequence some improvement, but not enough to enable it to be called anything else than foul.

At Millville, the lowest point at which samples have been taken, the water has lost some of its objectionable features, but it is still unfit for use for drinking. The mineral matters and chlorine at this point are not excessive, but the high free ammonia shows the continued presence of putrefying material.

The Merrimack River.

The Merrimack River is being studied (as shown in Tables IVa and b) at six points, from Nashua, N. H., to Haverhill, Mass., as well as at its head waters at Lake Winnepiseogee, and on four of its tributaries. If we compare the waters of the Lake with that of the Merrimack at Haverhill there is a striking difference in composition. The former is colorless and of high purity, and the latter is colored, and carries a good deal of organic and mineral matter in suspension and solution. Again, if we compare the two extremes on the river itself at Nashua and Haverhill we still notice a wide difference in character. At Haverhill the free ammonia is double that at Nashua, the albuminoid ammonia one and a half times as much, and there is a slight increase in the nitrates The fixed solids are increased fourteen per cent., the volatile solids eleven per cent., and the chlorine twelve per cent.

The changes between the stations immediately succeeding each other are less marked, but they are, in general, in the line of progressive contamination. As has been previously noted, the evidence derived from the solid contents and the chlorine is more uniform in this regard than that derived from the nitrogenous matter. In the latter we notice considerable fluctuation, but in the former the increase is quite uniform

The Merrimack is a good instance of the ability of a large river to receive a good deal of polluting material, in the

TABLE IV. "A."

MERRIMACK RIVER.

(ORGANIC CONTENTS). PARTS IN 100,000.

1887.	Winnipiseogee River, at Lake Village. Color.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates.	At Nashua.* Color.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates.	Above Lowell. Color.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates.	Opposite Lowell, above the Concord. Color.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates.
June,	0.0	.0002	.0076	.000	0.5	.0000	.0128	.007	0.4	.0020	.0122	.013	0.3	.0010	.0147	.013
July,	0.0	.0002	.0085	.000	0.4	.0002	.0143	.004	0.4	.0010	.0133	.003	0.4	.0002	.0170	.003
August,	0.0	.0005	.0077	.000	0.6	.0031	.0158	.007	0.0	.0027	.0177	.007	0.6	.0007	.0212	.007
September,	0.0	.0000	.0088	.007	0.15	.0011	.0160	.003	0.15	.0018	.0148	.007	0.2	.0022	.0182	.007
October,	0.0	.0000	.0098	.000	0.3	.0022	.0180	.007	0.4	.0042	.0152	.008	0.3	.0031	.0172	.010
November,	0.0	.0000	.0080	.003	0.35	.0018	.0196	.005	0.75‡	.0026	.0203	.009	0.75	.0012	.0209	.000
December,	0.0	.0000	.0107	.002	0.45	.0012	.0188	.010	0.4	.0007	.0169	.012	0.45	.0006	.0160	.011
Mean,	0.0	.0001	.0087	.002	0.39	.0015	.0106	.006	0.44	.0021	.0158	.008	0.43	.0014	.0182	.009

1887.	Above Lawrence.† Color.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates.	Below Lawrence. Color.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates.	Above Haverhill. Color.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates.
June,	0.4	.0006	.0159	.009	0.5	.0003	.0182	.000	0.45	.0018	.0181	.006
July,	0.4	.0026	.0174	.007	0.5	.0004	.0104	.007	0.4	.0008	.0160	.007
August,	0.55	.0046	.0206	.013	0.55	.0033	.0288	.013	0.5	.0037	.0251	.010
September,	0.3	.0015	.0103	.016	0.25	.0002	.0214	.007	0.35	.0073	.0213	.003
October,	0.5	.0036	.0108	.008	0.5	.0000	.0242	.005	0.4	.0028	.0235	.017
November,	0.65	.0018	.0225	.010	0.45	.0022	.0250	.010	0.5	.0024	.0240	.007
December,	–	–	–	–	0.45	.0014	.0183	.013	0.45	.0044	.0228	.012
Mean,	0.47	.0024	.0207	.011	0.40	.0011	.0222	.000	0.43	.0033	.0221	.009

* The station at Nashua is above the mouth of the Nashua River.

† The results given for the river "above Lawrence" are the mean of two analyses of the water at 1 foot and at 6 feet below the surface, opposite the Lawrence Pumping Station, 60 feet from the northeast shore.

‡ This sample taken two days later than the others in November.

TRIBUTARIES.

1887.	Nashua River, at Clinton. Color.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates.	Nashua River, at Nashua. Color.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates.	Assabet River, at Northborough. Color.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates.
June,	0.3	.0018	.0175	.006	0.4	.0060	.0185	.007	0.9	.0032	.0240	.013
July,	1.2	.0032	.0340	.013	0.5	.0022	.0245	.007	0.6	.0066	.0240	.013
August,	0.0	.0020	.0230	.005	0.7	.0039	.0193	.010	0.8	.0061	.0303	.003
September,	0.4	.0012	.0166	.008	0.2	.0026	.0101	.007	0.5	.0037	.0235	.003
October,	0.4	.0008	.0210	.008	0.6	.0054	.0106	.008	0.65	.0030	.0324	.010
November,	0.55	.0008	.0196	.006	0.4	.0030	.0214	.009	0.3	.0018	.0212	.009
December,	0.3	.0008	.0160	.008	0.45	.0027	.0105	.010	0.8	.0058	.0238	.008
Mean,	0.58	.0015	.0216	.008	0.40	.0039	.0203	.008	0.65	.0043	.0256	.008

1887.	Concord River, at Lowell. Color.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates.	Shawsheen River, at Wilmington. Color.	Free Ammonia.	Albuminoid Ammonia.	Nitrogen as Nitrates.
June,	–	–	–	–	0.9	.0013	.0232	.006
July,	–	–	–	–	1.5	.0010	.0440	.009
August,	–	–	–	–	1.0	.0016	.0431	.003
September,	–	–	–	–	0.2	.0005	.0110	.093
October,	–	–	–	–	1.3	.0010	.0260	.003
November,	0.8	.0074	.0375	.010	1.4	.0006	.0304	.007
December,	–	–	–	–	1.1	.0005	.0231	.020
Mean,	–	–	–	–	1.1	.0011	.0290	.006

TABLE IV. "B."

MERRIMACK RIVER.

(MINERAL CONTENTS). PARTS IN 100,000.

	Winnipiseogee River, at Lake Village.				
	Turbidity.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.
1887.					
June,	Slight,	2.35	1.00	1.35	.14
July,	None,	2.10	0.80	1.30	.14
August,	Very slight,	2.22	0.52	1.70	.13
September,	Slight,	2.22	0.60	1.62	.14
October,	Very Slight,	2.10	0.45	1.65	.10
November,	Very Slight,	2.05	0.65	1.40	.11
December.	Very Slight,	1.80	0.30	1.50	.14
Mean,	–	2.12	0.62	1.50	.13

	At Nashua.				
	Turbidity.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.
1887.					
June,	Slight,	4.37	1.05	2.42	.21
July,	Slight,	4.50	1.30	3.20	.12
August,	Very slight,	3.02	1.07	2.85	.12
September,	Distinct,	3.76	0.85	2.90	.18
October,	Distinct,	3.85	0.70	3.15	.18
November,	Decided,	4.25	1.20	3.05	.20
December.	Very decided,	*3.30	1.25	2.05	.12
Mean,	–	3.09	1.10	2.80	.18

	Above Lowell.				
	Turbidity.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.
1887.					
June,	Slight,	3.90	1.55	2.35	.16
July,	Very slight,	3.55	1.15	2.40	.12
August,	Very slight,	4.07	1.15	2.92	.14
September,	Slight,	3.95	0.80	3.15	.20
October,	Very slight,	3.85	0.70	3.16	.10
November,	Decided,	†5.15	1.25	3.00	.24
December.	Decided,	5.60	1.50	4.10	.15
Mean,	–	4.29	1.15	3.14	.17

	Opposite Lowell, above the Concord.				
	Turbidity.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.
1887.					
June,	Slight,	4.40	1.82	2.58	.20
July,	Slight,	4.25	1.25	3.00	.10
August,	Distinct,	4.75	1.35	3.40	.16
September,	Decided,	4.45	1.05	3.40	.22
October,	Very slight,	4.10	0.65	3.45	.22
November,	Decided,	5.85	1.50	4.35	.26
December.	Decided,	5.60	1.30	4.30	.10
Mean,	–	4.77	1.27	3.50	.20

	Above Lawrence.				
	Turbidity.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.
1887.					
June,	Distinct,	4.41	1.76	2.65	.17
July,	Distinct,	4.60	1.00	3.60	.17
August,	Decided,	6.40	1.40	5.00	.21
September,	Slight,	4.70	0.95	3.75	.25
October,	Slight,	4.80	0.85	3.95	.28
November,	Decided,	4.75	1.23	3.52	.24
December.	–	–	–	–	–
Mean,	–	4.94	1.20	3.74	.22

	Below Lawrence.				
	Turbidity.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.
1887.					
June,	Distinct,	5.85	2.17	3.68	–
July,	Distinct,	5.05	1.57	3.48	.17
August,	Decided,	6.37	1.15	5.22	.20
September,	Decided,	4.90	1.15	3.75	.25
October,	Distinct,	5.90	1.15	4.75	.29
November,	Distinct,	5.10	1.35	3.75	.24
December.	Decided,	5.65	1.50	4.16	.20
Mean,	–	5.55	1.43	4.11	.22

	Above Haverhill.				
	Turbidity.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.
1887.					
June,	Decided,	5.02	1.70	3.32	.16
July,	Distinct,	4.42	1.22	3.20	.13
August,	Decided,	6.70	1.05	5.65	.20
September,	Very Slight,	4.65	0.95	3.70	.22
October,	Decided,	5.35	1.45	3.90	.30
November,	Distinct,	5.30	1.55	3.75	.26
December.	Decided,	5.75	1.55	4.20	.22
Mean,	–	5.31	1.35	3.96	.21

* This sample was filtered. The unfiltered sample from Nashua contained 8.90, 1.70, 7.20.

† Taken two days later than the others in November.

TRIBUTARIES.

	Nashua River, at Clinton.				
	Turbidity.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.
1887.					
June,	Very slight,	4.22	1.17	3.05	.25
July,	Slight,	4.47	1.52	2.95	.15
August,	Slight,	4.15	1.42	2.73	.12
September,	Very slight,	3.90	1.05	2.85	.19
October,	Slight,	4.30	1.00	3.30	.27
November,	Slight,	4.05	1.40	2.65	.25
December,	Distinct,	3.85	1.10	2.75	.22
Mean,	–	4.13	1.24	2.89	.21

	Nashua River, at Nashua.				
	Turbidity.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.
1887.					
June,	Slight,	4.87	2.00	2.87	.43
July,	Slight,	5.00	1.35	3.65	.38
August,	Very slight,	4.02	1.00	3.92	.29
September,	Distinct,	4.90	0.85	4.05	.20
October,	Slight,	5.45	1.30	4.15	.35
November,	Decided,	5.55	1.30	4.25	.41
December,	Distinct,	4.35	1.20	3.72	.28
Mean,	–	5.01	1.29	3.72	.35

	Assabet River, at Northborough.				
	Turbidity.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.
1887.					
June,	Slight,	5.37	2.42	2.95	.27
July,	Very slight,	5.32	1.42	3.90	.23
August,	Slight,	5.35	1.67	3.68	.29
September,	Distinct,	4.85	1.20	3.05	.30
October,	Distinct,	5.40	1.30	4.10	.32
November,	Decided,	5.25	1.05	4.20	.31
December,	Slight,	4.70	1.45	3.25	.27
Mean,	–	5.18	1.50	3.68	.28

	Concord River, at Lowell.				
	Turbidity.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.
1887.					
June,	–	–	–	–	–
July,	–	–	–	–	–
August,	–	–	–	–	–
September,	–	–	–	–	–
October,	–	–	–	–	–
November,	–	7.05	2.35	4.70	.50
December,	–	–	–	–	–
Mean,	–	–	–	–	–

	Shawsheen River, at Wilmington.				
	Turbidity.	Total Solids.	Loss on Ignition.	Fixed Solids.	Chlorine.
1887.					
June,	None,	4.92	1.22	3.70	.34
July,	Very slight,	6.95	2.10	4.85	.33
August,	None,	7.30	2.75	4.55	.36
September,	None,	4.00	1.00	3.00	.38
October,	Very slight,	6.00	2.00	4.00	.48
November,	Slight,	7.00	2.55	4.45	.47
December,	Very slight,	6.50	1.80	4.70	.35
Mean,	–	6.09	1.92	4.18	.30

form of sewage and manufacturing refuse from large cities, without becoming seriously polluted. It has in this respect not only the advantage of large volume, but it is unusually well aerated by agitation in rapids, dams and water-wheels, which, without doubt, have some influence in counteracting the influence of the organic matter. How far the results of chemical analysis would have been different in a summer of normal rainfall it is impossible to say. By referring to the tables it will be seen that the water samples examined were very generally turbid, owing to the frequent and heavy rains.

The tributaries of the Merrimack which have been examined, namely, the Nashua, Assabet, Concord and Shawsheen, are all less pure than the Merrimack at the points of junction, and contribute therefore to the impurities of the Merrimack. The Shawsheen is characterized by its high color, and its corresponding high albuminoid ammonia. It is, however, generally clear and free from sediment.

III.

Purification of Sewage by Applying it to Land.

In England, France and Germany, and to a limited extent in this country, sewage has been satisfactorily purified by applying it to land used for growing crops, with the result that the water flowing from underdrains was nearly as good as the supplies of drinking water of those countries, so far as chemical and biological examinations could determine.

The quantity which can be applied depends upon the permeability of the soil and the underlying strata, the amount of rainfall and the character of the crops.

In England from 2,000 gallons per acre per day to 6,000 gallons have been applied, giving an average of a little more than 4,000 gallons per acre per day where the rainfall is twenty-two inches in the year.

In Germany about 3,000 gallons per day are recorded, and near Paris, in a very open sand, about 11,000 gallons per acre have been applied in raising cabbages, but this amount would drown the crops on any land that could be cultivated without irrigation.

It is probable that upon ordinary farm land in Massachusetts 2,500 gallons per day per acre are as much as could be applied to any valuable grass crop, and there would be required 400 acres of irrigation ground for each million gallons of sewage. Or the city of Lawrence, using sixty gallons of water per inhabitant, would require an irrigation field of 1,000 acres, or one quarter of the area of the city to use in irrigation the dry-weather sewage of the city.

We may then conclude that desirable as the use of sewage in irrigation is, we cannot depend upon irrigation alone in the more thickly settled parts of the State for preventing the pollution of streams.

The limit to the quantity that can be applied in irrigation is injury to the crop. Some kinds of land are found to be capable of purifying a much larger quantity of sewage than the crop can bear, if the sewage be applied at intervals of time, leaving the land to drain and become more or less filled with air between the applications. This method is known as *intermittent filtration*. By this method the suspended matter is retained near the surface, and is to a great degree burned up, and the liquid percolating in thin and broken laminæ comes in contact with the air, and much that is held in solution is given up or changed, and the effluent proves to be effectually purified.

This purification was at first supposed to be due to the oxidizing effect of the air, but the experiments of Schloesing of France, and Frankland and Warington of England, prove that with this there must be the active presence of organisms to produce nitrification.

Schloesing found by passing sewage through glass tubes filled with baked sand and with marbles, —

First. No purification was produced.

Second. After a while the effluent was quite clear and free from organic matter.

Third. Upon applying chloroform to the tube, purification stopped and did not commence again till all traces of the chloroform were washed out.

He was thus confirmed in the conclusion that purification requires the active co-operation of organic life.

No purifying or nitrifying effect being produced at first by sand, in which organic life had been destroyed by heat, and the nitrifying effect beginning after sewage had been some time passing through, he concluded that the sewage introduced the nitrifying elements, and that as their purifying action ceased when treated with chloroform and began again after the chloroform was washed out, he concluded these elements were living organisms.

Robert Warington in England has made many valuable experiments upon nitrification in soils and waters, and being confirmed in the view that it is due to living organisms has sought to determine the distribution of the nitrifying organism in the soil, and concludes that it is practically confined to the surface soil and occurs to a very small extent in a clay subsoil removed two or three feet from the surface.

Dr. Frankland of England, by experiments, passing sewage through two-inch glass tubes sixteen feet long, filled with sand or sand and chalk, found that about six gallons of London sewage can be satisfactorily purified per cubic yard in twenty-four hours. He concluded that purification is a process of oxidation, the products being carbonic and nitric acids, consequently a continual aeration of the soil is necessary.

With glass cylinders $10\frac{1}{2}$ inches in diameter filled with about five feet in depth of soil, he found, by applying sewage intermittently and at different rates to different soils, the following results: —

Darsley soil; a light brown loam, purified, 9.9 gallons per cubic yard in twenty-four hours.

Bennington soil; a porous gravel, which had been used five years for sewage irrigation, gave 7.6 gallons per cubic yard in twenty-four hours, of effluent "almost as good as London water."

Hambrook soil; a light reddish sand, did not at first purify but after a fortnight it began, but would not purify more than 4.2 gallons per cubic yard in twenty-four hours.

Barking soil; at first absorbed some fertilizing ingredients; but with 3.8 gallons in twenty-four hours showed increasing quantities of organic matter in the effluent for twelve weeks, and the effluent gradually became crude sewage.

The results with sand from Hambrook are like those obtained by Schloesing with sand and marbles. It took some time, in this case two weeks, before the effluent began to show nitrification; whereas when loam from Darsley was used, or soil from Bennington which had previously been treated with sewage, nitrification began immediately.

The conclusion reached was that in the loam, nitrifying organisms existed as shown by Warington, and nitrification set in at once, while they did not exist in the sand and gravel but were introduced by the sewage and were retained in passing over the particles of sand, where they multiplied till they were in sufficient number to effect the nitrification of the sewage.

At the Clichy Laboratory, near Paris, experiments were made in a plate-glass tank, six and a half feet high and about eight inches square. One inch in depth of Paris sewage was put upon this sand daily for five years, with the result that the sand was generally clean, after the five years' use.

The quality of the effluent was excellent as shown by the following analysis in parts in 100,000: —

	Sewage strained through Paper.	Effluent.
Ammoniacal nitrogen, ...	2.69	.02
Albuminoid nitrogen, ...	0.406	.01
Nitric nitrogen, ...	0.04	1.96
	3.14	1.99

Frankland's experiments with sand, and with sand and chalk, gave the following results when discharging 5.6 gallons per day per cubic yard, or 45,000 gallons per acre if five feet deep: —

	Sewage.	Effluent — Through Sand.	Effluent — Through Sand and Chalk.
Solids in solution, ...	64.5	77.6	94.6
Organic carbon, ...	4.386	.734	.582
Organic nitrogen, ...	2.484	.108	.092
Ammonia, ...	5.557	.012	.016
Nitrogen as nitrates and nitrites, . .	.000	3.925	3.478
Total combined nitrogen, ...	7.060	4.043	3.583

The effluent through Bennington soil, five feet deep at the rate of 61,000 gallons per acre per day, Dr. Frankland said was "almost as good as London water."

The quantities of sewage applied in intermittent filtration, in which we have satisfactory analyses of the effluent, are those of experiments on material in glass tubes having areas from three square inches to eighty-seven square inches, and the amount of sewage applied and satisfactorily purified varied from 30,000 gallons per acre per day to 80,000 gallons per acre, upon a bed five feet deep. One soil tested failed to purify the lesser amount.

The amounts reported as applied to various filter beds in England and on the Continent are from 36,000 to 90,000 gallons per acre per day, but the analyses of the effluent when given are not so satisfactory as those obtained in the laboratories. From these results it appears that filter beds, if of proper material, can purify ten or twelve times as much sewage per acre as can be applied to our farm lands in irrigation.

It is upon the basis of these results that we must enter upon experiments to determine the amount of sewage we can in this climate purify with such material as is deposited in our valleys.

At present no one can tell in regard to any area that may be selected the character of the effluent that will result from the application of sewage in large or small quantity, nor the effect of our winters nor of long storms upon the efficiency of the bed, nor the proper intervals for application.

This knowledge can be obtained only by trial and careful observation. To make such trials in the most economical way to obtain reliable information and actual additions to the knowledge of the world upon this subject for immediate and urgent use in this State, the Board of Health has established an experimental station and is now actively pursuing the investigation in regard, first to the soils, sands and gravels to be found in its neighborhood, afterward to be replaced by those which may be proposed for such use in other localities.

Sewage Experimental Station at Lawrence.

Wherever sewage is to be purified in any manner it is important on the ground of economy that it be collected and conveyed to the purifying grounds separate from and undiluted by storm water or surface drainage, and in seeking a location for experiments upon the filtration of sewage, a supply of ordinary city sewage undiluted by storm water was sought, but no such locality in the State being available the Board found many advantages in locating the experimental station in the city of Lawrence, upon the north bank of the Merrimack River, where land owned by the Essex Company was placed at its disposal for the purpose.

To this place sewage is conveyed in a two and a half inch pipe of galvanized iron, from a point in the main sewer of the city about 1,000 feet above its outlet, and above the entrance of streams from the manufacturing establishments; this sewage from stores and from the dwellings of perhaps 10,000 people may reasonably be regarded as ordinary city sewage, similar during very dry weather to sewage separate from storm water, but during wet weather very much diluted by surface drainage.

The iron pipe follows the sewer to its outlet, and there rests upon the bed of the river for 3,000 feet, then extends 300 feet within the filtering grounds.

The filtering grounds comprise about two-thirds of an acre with surface from fifteen to twenty feet above the river in summer. The material of the field is fine sand, known as river silt, deposited by the river upon its banks at times of freshet.

Within this area the Essex Company had constructed in former years, for its own use, a building three hundred feet long, and about ten feet wide, and ten feet high, nearly all below the surface of the ground, lighted by windows in the roof.

Within this building was a drain, and above this a wooden flume about two feet wide and one foot high, resting on piles, two at every five feet of its length, and sloping in its length about one foot in one hundred feet. This flume is divided at each twenty-five feet of its length by a tight partition, each section forming a basin twenty-five feet long, about two feet wide and one foot high, and containing between two and three hundred gallons. Each section is provided with an outlet by which its contents may be turned into the drain beneath.

Outside of the building, in the field, where the surface of the ground is seven and one half feet above the upper edge of this flume, opposite each of ten of the sections of twenty-five feet in length is placed a wooden tank, buried to its top.

These ten tanks were made of cypress, circular in plan, sixteen feet eight inches in diameter inside, at the bottom, seventeen feet four inches at the top, and six feet deep inside.

They were set with the bottom sloping four inches in its width toward the building, and the top of the staves cut level with the low side.

They rest upon mud sills and a bed of puddle, and before the sides were puddled in, the tanks were proved to be completely water tight.

From the lowest point in the bottom, a two-inch iron pipe, through the ground, conveys drainage from within the tank to the nearest section of the flume within the building.

In each tank fifteen feet in length of underdrain of horseshoe section, of about two square inches in area, is set half an inch above the bottom, and the floor covered with one layer of coarse gravel stones about one inch by two inches, this by another layer of smaller size, upon which follow layer after layer, decreasing in size to one eighth of an inch in diameter, and making a thickness of three and a half inches. This fine gravel is covered with very coarse mortar sand, with top surface level, three and one half inches deep in the middle of the tank.

Above this substratum the several tanks are filled as follows: —

Tank No. 1. Filled with five feet in depth of very coarse clean mortar sand, taken from a depth of six or eight feet.

Tank No. 2. Filled with five feet in depth of very fine, nearly white sand, taken from a pit below discoloration by weather.

Tank No. 3. Filled with peat, which is nearly all vegetable matter, but contains a little mud. The top of the peat bed which had been cultivated was removed and the tank filled four feet with the undisturbed lower layers, and one foot of the original top layer put on top.

Tank No. 4. Filled with five feet in depth of river silt, being mostly a very fine sand, from the excavation made in setting tank No. 5.

Tank No. 5. Filled five feet deep with an excellent quality of brown soil taken from a garden which had been cultivated many years, and manured and put down to grass last spring.

Tanks No. 6, 7 and 8. Filled to be as near alike as possible, with three feet eight inches of coarse and fine sand and fine gravel. Ten inches of yellow sandy loam, and six inches of brown soil, in the same position as found on the river bank, where it was covered with a poor growth of pine trees.

Tank No. 9. Filled four feet three inches deep with a very compact sandy hard pan of clay, sand and gravel, from Prospect Hill, Lawrence, covered with nine inches of brown soil.

In each case the filtering material was thrown scattering into water which partly filled the tank.

After filling each tank to a height three inches below the top, a little sloping bank one foot wide was filled around the inside of each tank, of the same material as the upper layer of the filter, to prevent the liquid applied reaching the side of the tank too freely.

Tank No. 10 is for the present used for the measurement of the rain fall and the evaporation.

Within the building at a higher level than the top of the tanks are placed two measuring basins, into which the sewage is pumped, and by a scale of heights indicating gallons the quantity to be put upon each filter tank is noted, and this quantity is distributed by movable hose to either of five tanks from one measuring basin, and to the other five tanks from the other measuring basin. Similar scales indicating gallons, in the basins in the building below the filter tank outlets, serve to measure the effluent from each of the filters.

Samples of crude sewage from the upper measuring tanks, and of the effluent from the lower measuring basins, are daily submitted to chemical and biological analysis.

In the field beyond the filter tanks the area of about one-third of an acre is sloped in the direction from the line of tanks about one foot in ten feet, and in the direction parallel with them about one foot in one hundred feet. This area is laid out in shallow drains to receive sewage for filtration, underdrains being placed sixty feet apart to catch samples of the effluent.

These underdrains are put at the depth of four feet, and slope like the surface, — one foot in ten feet, — being about fifty feet in length, opposite tanks Nos. 3 and 8, and opposite the space between Nos. 5 and 6.

Trenches were cut two feet wide and the bottom coated with two inches of puddling clay, plastered on a little lower in the middle where the two-inch drain tile was laid with open joints and surrounded with six inches in depth of gravel.

The surface drains are in the material of the field which for several feet in depth is a fine river silt, which freezes about as readily and compactly as clay. To guard against the interference of this hard freezing, shallow trenches, which follow the surface of the field in slopes, 1 foot in 30 feet, 1 foot in 50 feet, and 1 foot in 100 feet, were dug out one foot wide, with the bottom level of the same width, and of the following depths: No. 1, 6 inches deep; No. 2, 1 foot deep; No. 5, 3 feet deep; No. 6, 2½ feet deep; and filled in to these depths with coarse mortar sand similar to tank No. 1.

Trench No. 7 was dug out 1½ feet wide and 2 feet deep; and trench No. 8, 2 feet wide and 1½ feet deep, and filled with the same sand. These trenches are filled with coarse sand of the different depths and widths, to determine how much of such material is necessary to prevent trenches in river silt from freezing, and preventing filtration in the coldest weather. These trenches have the surface of the sand about four inches below the level of the ground adjacent, except near their lower end, where in fifty feet it increases to ten inches below.

They are about five feet apart, and in length as follows: No. 1, 113 feet; No. 2, 152 feet; No. 3, 195 feet; No. 4, 221 feet; No. 5, 176 feet; No. 6, 218 feet; No. 7, 203 feet; No. 8, 177 feet.

Before applying sewage to the tanks and trenches it was thought best to see what effect these several filtering materials would produce upon drinking water, and at the same time to determine the limiting quantity that could be passed through a layer of each material five feet deep most completely underdrained.

With this in view arrangements were made with the Water Board of the city of Lawrence to supply the experimental station with water, free of cost to the State, the Board of Health communicating to the Lawrence Water Board such results of its experiments upon drinking water as may be of service to that Board.

The results of these experiments made to the present time are now given in detail for each tank: —

Filter Tank No. 1.

Filled with very coarse mortar sand. The tank contains about 9,500 gallons of sand which was thrown into water and left saturated a month, when the water which flowed out readily amounted to 1,200 gallons in one hour, and 1,750 gallons in one and one-half hours, after which the rapidity of flow gradually decreased, 2,100 gallons having flowed out in 14 hours and 2,220 gallons at the end of 72 hours when the rate of flow was six-tenths of a gallon in an hour.

About one-fifth of the cubic contents of the tank flowed out in two hours.

The drainage was continued one week, during which time 145 gallons of rain fell into the tank, 150 gallons of the effluent came from the gravel and underdrains, and the filtering material contained a little more than 2,000 gallons of air.

Sand similar to this in tank No. 1 has been examined and found to contain about 35 per cent. of air space when perfectly dry. It follows that at this time this tank of 9,500 gallons of sand contained 2,000 gallons of air and 1,325 gallons of water.

Into this was poured daily 136 gallons, or the equivalent of one inch in depth over the surface of the sand, of water drawn from the city service pipes from November 14 to November 20; then 408 gallons daily from November 21 to November 26; none added on November 27; 544 gallons daily from November 28 to December 6; 1,000 gallons daily from December 7 to December 11; and 4,000 gallons daily from December 12 to December 16.

This water being applied with considerable care, to spread it over the surface, must have pushed before it a large part of the 1,325 gallons already in the tank, before it appeared at the outlet; how large a part we have not yet the means of determining with certainty. Probably it did not appear until 1,000 gallons had passed out, or until seven days after the first of the 136 gallons was applied. Comparing the quality of the water applied with that which flowed out after 1,000 gallons had passed after each change in quantity, we have given in the following table the mean result of the chemical analyses of applied water, and the effluent from this tank during the application of each of the quantities of water.

These results show a progressive improvement in the filtered water for the five weeks that the filter was in use, up to the end of filtering 1,000 gallons per day, and a slight decrease in percentage of impurities removed while 4,000 gallons per day were flowing through.

The general results at this tank to December 16 are: Removing the color completely; reducing the organic matter to $\frac{1}{2}$; reducing the free ammonia to $\frac{1}{4}$; reducing the albuminoid ammonia to nearly $\frac{1}{4}$; reducing the chlorine to $\frac{6}{7}$, and reducing the nitrates to $\frac{3}{4}$ of the amounts in the applied water.

From December 17 to 23 this tank was supplied with 230 gallons daily of effluent from tank No. 5, which is filled with garden soil, with the mean result given in the table.

The color was removed. The organic matter, which is the loss on gently igniting the solid residue on evaporation of the water, reduced to one-quarter and the ammonia to one-seventeenth of the applied water; the chlorine reduced from 0.45 to 0.24 and the nitrates unchanged.

From December 24 to December 30 this tank was again supplied with 4,000 gallons of city water per day, with nearly the same general result as when previously applied.

TANK NO. 1. (Parts in 100,000.)

	No. of Analyses.		Residue on Evaporation.			Ammonia.		Chlorine.	Nitrogen as Nitrites and Nitrates.
			Total.	Loss on Ignition.	Fixed.	Free.	Albuminoid.		
		While applying 136 gallons of water daily, Nov. 14 to 20, —							
Applied water,	1	. . . .	4.40	1.15	3.25	.0034	.0144	.30	.020
Effluent, . .	1	. . . .	5.10	0.75	4.35	.0010	.0070	.36	.020
		While applying 408 gallons of water daily, Nov. 21 to 26, —							
Applied water,	1	. . . .	4.30	1.35	2.95	.0016	.0104	.28	.018
Effluent, . .	3	. . . .	3.75	0.85	2.90	.0008	.0059	.26	.014
		While applying 544 gallons of water daily, Nov. 28 to Dec. 6, —							
Applied water,	7	. . . .	4.29	1.39	2.90	.0020	.0137	.31	.018
Effluent, . .	3	. . . .	3.19	0.58	2.61	.0003	.0029	.27	.015
		While applying 1,000 gallons of water daily, Dec. 7 to 11, —							
Applied water,	4	. . . .	4.46	1.08	3.38	.0026	.0132	.33	.020
Effluent, . .	2	. . . .	3.12	0.62	2.50	.0002	.0027	.30	.016
		While applying 4,000 gallons of water daily, Dec. 12 to 16, —							
Applied water,	5	. . . .	4.30	1.42	2.88	.0026	.0134	.28	.019
Effluent, . .	3	. . . .	3.23	0.68	2.55	.0012	.0043	.24	.012
		While applying 230 gallons daily of effluent from Tank No. 5, Dec. 17 to 23, —							
Applied water,	4	. . . .	9.96	3.02	6.94	.0770	.0673	.45	.008
Effluent, . .	3	. . . .	4.33	0.72	3.61	.0009	.0077	.24	.008
		While applying 4,000 gallons of water daily, Dec. 24 to 30, —							
Applied water,	3	. . . .	4.08	1.07	3.01	.0033	.0143	.20	.010
Effluent, . .	4	. . . .	3.21	0.51	2.70	.0015	.0069	.23	.018

Filter Tank No. 2.

From 8,500 gallons of fine sand in this tank 650 gallons of water or seven and a half per cent. of the contents flowed out readily. Of this, 500 gallons flowed out in 22 hours and 150 gallons in 42 hours more.

After draining six days 830 gallons had flowed out and 145 gallons had been supplied by rain, leaving in the 8,500 gallons of sand 685 gallons of air.

The sand of this tank and the material of the other tanks to follow has not yet been examined to determine how much water can be added to saturate a perfectly dry mass of it, but it will for present purposes be assumed to be three-tenths of the whole mass, except in case of tank No. 3.

Three-tenths of 8,500 gallons gives us 2,550 gallons of water when saturated, but 685 gallons had been withdrawn, leaving in the tank 1,865 gallons of water and 685 gallons of air.

Into this were poured 136 gallons of city water daily, from November 14 to November 26; 272 gallons daily, from November 28 to December 11; and 1,000 gallons daily, from December 12 to December 18, after which sewage was applied. The mean results of the chemical examinations for each stage are given in the following table: —

TANK No. 2. (Parts in 100,000.)

	No. of Analyses.		Residue on Evaporation. Total.	Residue on Evaporation. Loss on Ignition.	Residue on Evaporation. Fixed.	Ammonia. Free.	Ammonia. Albuminoid.	Chlorine.	Nitrogen as Nitrites and Nitrates.
		While draining water from tank, Nov. 8 to Nov. 11, —							
Effluent, . .	3	. . . .	5.20	1.12	4.08	.0012	.0067	.33	.007
		While applying 136 gallons daily, Nov. 14 to Nov. 26, —							
Applied water,	2	. . . .	4.35	1.25	3.10	.0025	.0124	.29	.019
Effluent, . .	4	. . . .	3.70	0.80	2.90	.0015	.0048	.38	.007
		While applying 272 gallons daily, Nov. 28 to Dec. 11, —							
Applied water,	10	. . . .	4.36	1.26	3.10	.0023	.0136	.31	.019
Effluent, . .	5	. . . .	2.88	0.80	2.08	.0006	.0030	.32	.010
		While applying 1,000 gallons daily, Dec. 12 to Dec. 18, —							
Applied water,	6	. . . .	4.28	1.39	2.89	.0025	.0133	.28	.019
Effluent, . .	2	. . . .	2.35	0.57	1.78	.0002	.0024	.27	.013
		While applying 136 gallons of sewage daily, Dec. 19 to 23, —							
Sewage, . .	3	. . . .	37.03	18.63	18.40	.8093	.3250	3.17	.006
Effluent, . .	1	. . . .	3.90	1.55	2.35	.0058	.0044	.36	.020
		While applying 272 gallons of sewage daily, Dec. 24 to 30, —							
Sewage, . .	2	. . . .	41.70	20.20	21.50	1.5100	.6000	3.56	.006
Effluent, . .	3	. . . .	4.35	1.47	2.88	.0032	.0079	0.69	.006

The applied waters of each stage are compared with the effluent which came after 1,800 gallons had flowed out after the beginning of the application.

These results show a very decided improvement in the filtered water the longer the filter was used and the greater the quantity of water put on daily; the organic matter burned out decreasing from 0.80 to 0.57, and the sum of the ammonia from .0063 through .0036 to .0026, and the nitrates increased from .007 through .010 to .013.

The final results, which are the best, are with 1,000 gallons a day flowing through the tank and are: Removing the color completely; reducing the organic matter to $\frac{4}{10}$; reducing the free ammonia to $\frac{1}{12}$; reducing the albuminoid to $\frac{1}{6}$; leaving the chlorine unchanged; reducing the nitrates to $\frac{3}{4}$ of the amounts in the applied water.

City sewage was applied to tank No. 2 from December 19 to 23, at the rate of 136 gallons per day, when it was increased to 272 gallons per day.

The results are presented in the table, and up to the present time show an effluent which is chemically about as good as the city water which has been applied previously, but the chlorine and albuminoid ammonia have been increasing since the sewage began to come through, and further time is necessary before making a conclusion as to the continued action of this filter upon this quantity of sewage. The effluent is bright, clear and colorless.

Filter Tank No. 3.

From 8,500 gallons of muck 230 gallons flowed out in twenty-four hours, and 500 gallons in one hundred and seven hours, when the rate of flow was about two gallons per hour, but the amount of air left in the muck cannot be stated, because as the water flowed out the muck settled.

The water began to flow out November 9. Up to November 17, 136 gallons of water had been put on from the city main, and 334 gallons from rain, making 470 gallons applied. Eight hundred and twenty-six gallons had flowed out and near an inch in depth stood upon the surface; this with ninety-four gallons from rain, kept water upon the surface till November 26, when it disappeared, and the surface was left to dry till December 3, from which date to December 13 fifty gallons per day were applied, but this accumulating on the surface was discontinued.

The quantity flowing through the tank has gradually decreased until it has become less than one gallon an hour, although the surface is continually covered with water.

The quality of the water flowing from this tank after the first two weeks has been nearly constant, and is expressed by the following mean of ten chemical examinations:—

Total residue on evaporation,	13.20
Loss on ignition,	3.07
Fixed,	10.13
Free ammonia,	.0058
Albuminoid ammonia,	.0239
Chlorine,	1.26
Nitrogen as nitrites and nitrates,	.017
Nitrites,	Present.

The applied water consisted of about 510 gallons of rain and 636 gallons of city water.

The color of effluent was less than that of applied water.

The organic matter is more than doubled.

The ammonias are higher than those of the city water, and lower than those of the rain water.

The chlorines are greatly increased, being four times those of the city water, but are growing less.

The nitrates have increased from .012 to .018, and in the latter half of the time have been about the same as those of the city water.

On the whole the effluent from this tank is not as good as the applied water, and the small amount that passes through renders this material of little value as a filtering material. This amount is but 1,800 gallons per day per acre, in excess of the average rain falling upon it.

From December 26, city sewage to the amount of twenty-five gallons has been applied daily, and when rain fell in sufficient quantity to cover the surface it has been bailed out; seventy-five gallons being taken out on December 29.

Up to the present time no effect of sewage is noticeable in the effluent, probably none has gone entirely through the filtering material.

Filter Tank No. 4.

From 8,500 gallons of river silt, 550 gallons of water flowed out in seventy-eight hours without appreciable settlement of the sand, although the surface cracked. The sand then contained about 550 gallons of air, and about 2,000 gallons of water. Into this was poured daily 136 gallons of water from November 14 to 26, and 272 gallons daily from November 28 to December 7.

On one of these days, December 1, when the temperature was 4°, the surface of this tank froze and prevented the passage of water. Outside of the tank river silt was found to be frozen to a depth of eight inches, or about equal to that of clayey hard pan.

Continued application of the water at temperature of about 40° on the following day caused the frozen surface to melt and let water through. To avoid stopping the experiments on this tank in still colder weather a change was made in the surface by excavating trenches, and filling them with the coarse sand, like that in tank No. 1. The outer trench was one foot from outside of tank, one and one half feet deep and two feet wide. The inner trench was five feet from the outside, two feet deep and one and one half feet wide, and in the centre was excavated and filled with the sand, a cylinder sixteen inches in diameter, and three feet deep. These trenches receive the water immediately below the surface, and enable a much larger quantity of water to be put upon this tank than formerly.

The maximum flow from the tank when 136 gallons were applied was fifteen gallons per hour. When 272 gallons were applied it was 24 gallons per hour before the change, and 65 gallons per hour after the change; and with 1,000 gallons per day the maximum flow was 110 gallons per hour.

After the change the amount of water left in the tank when drained, after 272 gallons were applied, was probably about 1,700 gallons. The 272 gallons were continued daily from December 8 to 11, and 1,000 gallons daily from December 12 to 18, then 136 gallons of sewage were applied daily from December 19 to 23, and 272 gallons of sewage from December 24 to 31.

The mean results of the chemical analyses for each quanity applied are given in the following table :—

Tank No. 4. (Parts in 100,000.)

	No. of Analyses.		Residue on Evaporation.			Ammonia.		Chlorine.	Nitrogen as Nitrites and Nitrates.
			Total.	Loss on Ignition.	Fixed.	Free.	Albuminoid.		
		While drawing water from tank, Nov. 11 to 14,—							
Effluent, . .	2	. . . .	8.20	1.15	7.05	.0031	.0083	.33	.009
		While applying 136 gallons of water daily, Nov. 14 to 26,—							
Applied water,	2	. . . .	4.35	1.25	3.10	.0025	.0124	.29	.019
Effluent, . .	4	. . . .	8.53	1.44	7.09	.0060	.0126	.39	.012
		While applying 272 gallons of water daily, Nov. 28 to Dec. 7,—							
Applied water,	7	. . . .	4.29	1.24	3.05	.0021	.0139	.31	.018
Effluent, . .	4	. . . .	7.37	1.30	6.07	.0099	.0084	.32	.014
		While applying 272 gallons daily, after change in surface of tank, Dec. 8 to 11,—							
Applied water,	3	. . . .	4.53	1.32	3.21	.0026	.0128	.30	.021
Effluent, . .	1	. . . .	5.80	1.40	4.40	.0090	.0080	.32	.030
		While applying 1,000 gallons of water daily, Dec. 12 to 18,—							
Applied water,	6	. . . .	4.28	1.39	2.89	.0025	.0133	.28	.019
Effluent, . .	4	. . . .	4.26	0.74	3.52	.0064	.0069	.24	.029
		While applying 136 gallons of sewage, Dec. 19 to 23,—							
Sewage, . .	3	. . . .	37.03	18.63	18.40	.8093	.3250	3.17	.006
Effluent, . .	1	. . . .	5.65	1.85	3.80	.0072	.0060	.63	.058
		While applying 272 gallons of sewage, Dec. 24 to 31,—							
Sewage, . .	2	. . . .	41.70	20.20	21.50	1.5100	.6000	3.56	.006
Effluent, . .	3	. . . .	9.27	2.43	6.84	.0089	.0083	2.42	.037

The effluent from the original tank was not as good as the applied water, nor did it improve after the change, while 272 gallons were applied.

Before and after the change when 272 gallons were applied the results were :—

The removal of color; a considerable increase in the fixed solids; a slight increase of organic matter; a large increase in the free ammonia, with a decrease in the albuminoid ammonia, leaving the sum of the ammonias ten to fifteen per cent. greater; the chlorine unchanged; and the nitrates at first less became greater than in the applied water. While 1,000 gallons were applied to the changed material the effluent improved and became better than the applied water, and continued improving, while the lesser quantity of 136 gallons daily was passing through after the application of sewage to the top and before it reached the bottom. The sewage applied on December 19 gave the first indication of reaching the outlet on December 27 by a slight increase in the chlorine from 0.23 of the previous days to 0.29, but on December 29 it became certain by the increase of the chlorine to 0.63, of the nitrates from .032 to .058, and of the organic matter from 0.87 to 1.85.

The effluent from sewage has to the present time continued to increase in impurities, and on January 5 the organic matter was twenty per cent.; the free ammonia one half of one per cent.; and the albuminoid ammonia one and one quarter per cent. of that of the applied sewage. The chlorine had increased to three quarters of that of the sewage, and the nitrates had increased sevenfold.

Filter Tank No. 5.

From the 8,500 gallons of garden soil, 400 gallons of water drained out in seventy-four hours when the rate of flow became one and one half gallons per hour.

There was slight settlement and some cracking of surface, which cracks were afterwards filled with soil. This tank is regarded as then containing 2,100 gallons of water.

There were applied 136 gallons of city water daily from November 14 to 26, and 272 gallons were applied daily for a week, after which some accumulated on the surface and the quantity was gradually reduced to 230 gallons, which was continued to December 23. The water evidently dissolved impurities from the soil in increasing quantities till December 9, after which the quantities remained nearly constant.

The mean results of the chemical analysis for each quantity applied are given in the following table : —

TANK No. 5. (Parts in 100,000.)

	No. of Analyses.		Residue on Evaporation.			Ammonia.		Chlorine.	Nitrogen as Nitrites and Nitrates.
			Total.	Loss on Ignition.	Fixed.	Free.	Albuminoid.		
		While drawing water from tank, Nov. 12, —							
Effluent, . .	2	. . . .	11.42	1.75	9.67	.0019	.0198	.45	.003
		While applying 136 gallons of water daily, Nov. 14 to 26, —							
Applied water,	2	. . . .	4.35	1.25	3.10	.0025	.0124	.29	.019
Effluent, . .	3	. . . .	12.16	3.23	8.93	.0797	.0647	.64	.005
		While applying from 272 gallons to 230 gallons daily, Nov. 28 to Dec. 23, —							
Applied water,	18	. . . .	4.28	1.30	2.98	.0024	.0134	.29	.018
Effluent, . .	13	. . . .	10.51	3.17	7.34	.0800	.0636	.45	.007

The color of the effluent, slight at first, grew deeper as the experiments continued, but not as deep as that of the applied water. The fixed and volatile solids were both increased nearly two and a half times that of the applied water. The free ammonia was increased to thirty times and the albuminoid ammonia five times that of the applied water.

The chlorine was doubled and the nitrates decreased to one third, but as the use continued the chlorine at first large grew less, approaching that of the applied water, and the nitrates, at first small, increased, to be nearer that of the applied water.

Filter Tank No. 6.

From 8,500 gallons of material consisting of about 6,236 gallons of gravel and sand, 1,414 gallons of yellow subsoil and 850 gallons of brown soil, about 950 gallons of water flowed out in forty hours, ending with a rate of flow of four gallons per hour, which rate was rapidly decreasing. The tank then contained 950 gallons of air, which was one-ninth of its volume, and probably 1,600 gallons of water. Into this was poured daily 136 gallons of water from November 16 to 26, then 272 gallons from November 28 to December 14. On December 15 the six inches of soil was removed from the tank and the water applied directly to the surface of the yellow subsoil.

The mean results of the chemical analyses for each quantity applied are given in the following table : —

Tank No. 6. (Parts in 100,000.)

	No. of Analyses.		Residue on Evaporation.			Ammonia.		Chlorine.	Nitrogen as Nitrites and Nitrates.
			Total.	Loss on Ignition.	Fixed.	Free.	Albuminoid.		
		Water drawn before applied water, —							
Effluent, . .	1	. . . .	5.45	0.95	4.60	.0010	.0066	.84	.000
		When 136 gallons were applied daily, Nov. 16 to Nov. 26, —							
Applied water,	2	. . . .	4.35	1.25	3.10	.0025	.0124	.29	.019
Effluent, . .	2	. . . .	5.17	0.85	4.32	.0007	.0041	.75	.001
		When 272 gallons were applied daily, Nov. 28 to Dec. 14, —							
Applied water,	13	. . . .	4.40	1.31	3.09	.0022	.0134	.31	.019
Effluent, . .	7	. . . .	3.68	0.66	3.02	.0005	.0030	.32	.001
		When 272 gallons were applied daily to subsoil, Dec. 15 to 29, —							
Applied water,	7	. . . .	3.99	1.20	2.79	.0029	.0133	.26	.015
Effluent, . .	7	. . . .	3.01	0.59	2.42	.0004	.0035	.23	.006

These results show the water much improved from the first, and an increased improvement with continued use. With 136 gallons applied daily the color was entirely removed; the organic matter was reduced from 1.25 to 0.85; the free ammonia was reduced from .0025 to .0007, and the albuminoid ammonia from .0124 to .0041. The chlorine was increased from .29 to .75, and the nitrates decreased from .019 to .001.

While applying 272 gallons the efficiency of the filter increased, reducing the impurities generally 25 per cent. more, and bringing the chlorine to agree with that of the applied water. After removing the soil from the tank, and applying the water directly to the subsoil for two weeks, the remaining material gave results nearly identical with those obtained with the soil, showing in this case that the soil was of no advantage or disadvantage in filtering this drinking water.

On December 30, the ten inches of yellow subsoil being removed, water is now applied directly to the surface of the sand and gravel.

Filter Tank No. 7.

This tank, filled with similar material to No. 6, when saturated yielded 1,200 gallons in forty hours without apparent settlement, ending with a rate of flow of about three gallons per hour, and estimated as then containing 1,300 gallons of water. Into this 8,500 gallons of material containing about 1,200 gallons of air and 1,300 gallons of water, 272 gallons of water were applied daily from November 16 to November 26; 408 gallons daily were put on after November 28, when the tank would receive it, but owing to frost a part of the time and silting up of the surface the quantity applied was less. From November 28 to December 7 it averaged 362 gallons; from December 8 to 14, 364 gallons, and from December 15 to 27, 312 gallons.

The mean results of the chemical analyses for each stage are given in the following table:—

TANK NO. 7. (Parts in 100,000.)

	No. of Analyses.		Residue on Evaporation.			Ammonia.		Chlorine.	Nitrogen as Nitrites and Nitrates.
			Total.	Loss on Ignition.	Fixed.	Free.	Albuminoid.		
		While applying 272 gallons daily, Nov. 16 to 26, —							
Applied water,	2	. . . .	4.35	1.25	3.10	.0025	.0124	.29	.019
Effluent, . .	3	. . . .	4.55	0.78	3.77	.0005	.0054	.41	.001
		While applying about 362 gallons daily, Nov. 28 to Dec. 7, —							
Applied water,	7	. . . .	4.29	1.24	3.05	.0021	.0139	.31	.018
Effluent, . .	5	. . . .	3.74	0.64	3.10	.0003	.0024	.33	.001
		While applying about 364 gallons daily, Dec. 8 to 14, —							
Applied water,	6	. . . .	4.53	1.39	3.14	.0023	.0129	.31	.020
Effluent, . .	4	. . . .	3.10	0.64	2.46	.0003	.0029	.29	.001
		While applying about 312 gallons daily, Dec. 15 to 27, —							
Applied water,	6	. . . .	3.93	1.20	2.73	.0029	.0132	.24	.016
Effluent, . .	6	. . . .	3.07	0.42	2.65	.0005	.0031	.23	.001

The result, generally stated, is a decided improvement of the water from the first, with increased improvement for a month, after which the effluent remained nearly constant with the following relation to the applied water: The color was completely removed; the fixed solids were reduced slightly; the organic matter from 1.20 to 0.42; the free ammonia reduced from .0029 to .0005, and the albuminoid ammonia from .0132 to .0031; the chlorine unchanged, and the nitrates reduced from .016 to .001.

Filter Tank No. 8.

This tank, filled with material similar to that of No. 6 and of No. 7, when saturated yielded 1,150 gallons in 40 hours without apparent settlement, ending with a rate of flow of about three gallons per hour.

Into this 8,500 gallons of material containing about 1,150 gallons of air (and probably 1,400 gallons of water), 408 gallons of water were poured daily from November 16 to 26; then an average of 475 gallons per day from November 28 to December 7, after which an effort was made to keep the tank continually covered with water, and from December 8 to 16 the average quantity flowing through was 564 gallons per day. On December 16 a faucet was attached to the outlet and the stream regulated so that no air should enter the tank through the drain pipe.

The mean results of the chemical analyses are given in the following table: —

TANK No. 8. (Parts in 100,000.)

	No. of Analyses.		Residue on Evaporation.			Ammonia.		Chlorine.	Nitrogen as Nitrites and Nitrates.
			Total.	Loss on Ignition.	Fixed.	Free.	Albuminoid.		
		While applying 408 gallons of water daily, Nov. 16 to 26,—							
Applied water,	2	. . . .	4.35	1.25	3.10	.0025	.0124	.29	.019
Effluent, . .	2	. . . .	3.85	0.42	3.43	.0006	.0046	.34	.000
		While applying about 475 gallons of water daily, Nov. 28 to Dec. 7,—							
Applied water,	7	. . . .	4.29	1.24	3.05	.0021	.0139	.31	.018
Effluent, . .	4	. . . .	3.37	0.57	2.80	.0004	.0029	.31	.003
		While applying about 564 gallons of water daily, Dec. 8 to 16,—							
Applied water,	10	. . . .	4.36	1.23	3.13	.0025	.0133	.30	.019
Effluent, . .	3	. . . .	2.92	0.40	2.52	.0002	.0024	.26	.005
		Applying about 446 gallons daily, with air excluded, Dec. 17 to 31,—							
Applied water,	5	. . . .	3.99	1.11	2.88	.0031	.0134	.20	.011
Effluent, . .	9	. . . .	2.92	0.35	2.57	.0006	.0034	.24	.006

For the first month there was a continually increasing improvement in the quality of the effluent. The color was entirely removed. The organic matter that could be burned out of the applied water being 1.24 became in the effluent 0.42, 0.57 and 0.40 successively. The free ammonia from .0025 became .0006, .0004 and .0002; and the albuminoid ammonia from .0132 became .0046, .0029 and .0024. The chlorine from 0.30 became 0.34, 0.31 and 0.26, while the nitrates from 0.19 in the applied water became successively, .000, .003 and .005.

After air was excluded from the top and bottom of the filtering material the ammonias slowly became a little higher, but the change has been very slight in the two weeks of the trial.

Filter Tank No. 9.

This tank filled with 7,200 gallons of clay, sand and gravel such as forms the hard pan of many drift-hills in Eastern Massachusetts, covered with 1,300 gallons of brown soil, discharged 400 gallons of water in one month. No water was put upon the surface because it was kept continually covered by rain. The first 200 gallons had a slight tinge of color. Its volatile solids amounted to 4.50 and fixed solids to 14.63; the free ammonia to .0047 and albuminoid ammonia to .0129, chlorine to 2.33 and nitrates to .003.

The last 200 gallons had no color. The volatile solids amounted to 4.75; the fixed solids to 13.79; the free ammonia to .0013; the albuminoid ammonia to .0064; the chlorine to 2.88 and the nitrates to .003.

This appears to be a result slowly changing for the better.

The analysis of the principal rain which fell in this month showed it to have .0390 of free ammonia, .0124 of albuminoid ammonia, .04 of chlorine and .002 of nitrates, but it is not certain that any of this rain water reached the outlet of the tank.

It is important to know the characteristics of this material as affecting the water of wells, but it allows so little water to pass through that it has no value as a filter upon which to apply sewage. After draining one and one-half months, and being kept covered with water, the rate of flow is but twelve gallons per day, which is about seven-tenths of the average rainfall upon this area.

On December 30 a hole was cut in the surface of this tank nine inches through soil and six inches into wet puddling material, and a wooden conductor six inches square inside and four feet long, set vertically in the hole and filled around tight with the material excavated and a further bank of soil built up around it. This box stands fifteen inches into the material of the tank and the top stands two feet nine inches above the surface.

Since December 30 this box has been supplied with ten gallons of sewage daily, that the effluent may show the effect of sewage draining constantly through such material into a well.

The water applied to the tanks and the effluent have been subjected to careful microscopical examination by Mr. G. H. Parker of Cambridge with the following general result: —

Of the twelve plant forms and one animal form represented by many of each kind found in the applied water, none have been found in the effluent.

In the effluent from most of the tanks have been found a very few representatives of two plant forms and in that from one tank of three plant forms and one animal. The plants found are characteristic of ground waters and are supposed to act as purifiers by living upon the organic matter.

Dr. Edward K. Dunham, bacteriologist of the Board, has taken samples of the applied water and the effluent from each of the filters every other day during the month of December, and determined the number of bacteria in each sample by culture plates.

He is not yet ready to report upon the difference of species of those applied and those coming from the filters.

The following table gives the average number of viable bacteria in one cubic centimeter of water taken from each source during the month of December: —

Applied water,	68	No. 5,	49
No. 1,	20	6,	17
2,	20	7,	18
3,	36	8,	55
4,	21	9,	107

The number of bacteria found in a cubic centimeter of the applied sewage averaged 193,000. On January 3 the effluent from tank No. 2 contained 6,618 and on January 5 over 10,000; and the effluent from tank No. 4 on January 3 contained 95 and on January 5 a great increase; and some of the species from the effluent are the same as in the sewage.

Recommendations.

The Board recommends the continuation through the summer and fall of the monthly examination of all of the drinking waters of the State which are subject to pollution by sewage or by low stages of ponds and streams, which owing to the unusual rainfall of the past summer were not then found in an ordinary summer condition, and the continuation of the analysis of such other waters at intervals as may appear desirable.

The Board also recommends the active prosecution of the experiments upon the purification of sewage, recently commenced, through the coming year, and the prosecution of such additional investigations as may become necessary to properly interpret the results of the examination of water and of sewage.

For these purposes and to make the necessary investigations in order to advise cities, towns, corporations and individuals in regard to the best method of assuring the purity of intended or existing water supplies, and the best method of disposing of their sewage, and to carry out the other provisions of chapter 274, the Board estimates that the sum of $25,000 will be required.

H. P. WALCOTT,
T. K. LOTHROP,
H. F. MILLS,
E. U. JONES,
J. H. APPLETON,
F. W. DRAPER,
T. C. BATES,
State Board of Health.

REPORT OF THE CHIEF ENGINEER.

To H. P. Walcott, M. D., *Chairman State Board of Health.*

Sir : — Herewith is submitted a report for the year ending Dec. 31, 1887, of work done by the engineering department of the Board in compliance with the provisions of chapter 274, Acts of 1886.

The main work of this department during the year may be divided into two classes : (1), the examination of proposed plans or schemes of water supply or sewerage submitted by the various cities and towns ; (2), the examination of existing water supplies and inland waters of the State with reference to their purity. Much time has also been devoted to work in connection with chapter 95 of the Resolves of 1887, relating to the disposal of the sewage of the Mystic and Charles River valleys, of which no report will be made here.

The engineering force employed at the beginning of the year has been increased by the addition of two assistants to the permanent force. Other temporary assistants have been employed from time to time as their services were needed, chiefly on work connected with water examinations.

Examination of Proposed Plans of Water Supply and Sewerage.

Under the provision that all city and town authorities and corporations shall submit to the Board for its advice outlines of their proposed plans and schemes in relation to water supply and sewerage, many plans have been submitted. These cases and the action taken upon them are described in the accompanying report of the Board.

Following the established policy of your Board, I have made careful examinations of the location of proposed works of water supply and sewerage, and of such other localities in the vicinity as it seemed necessary to consider in order to advise as to the most appropriate source of water supply, or the best method of disposal of the sewage. In addition to these examinations all available information relating to the project has been gathered as a basis for a written report to your Board. During the year seven such reports have been made relating to water supply and eleven relating to sewerage.

In addition to these examinations and reports, four cases have been specially submitted to Mr. Joseph P. Davis, the consulting engineer of the Board, who has made an examination and has also reported in writing. In most of the other cases he has considered the schemes in a more general way and has furnished advice verbally.

Some of the cases presented during the year have been very important, and have required an extended investigation to develop the facts required as a basis for sound advice. Among these may be mentioned the application of the cities of Boston, Chelsea and Somerville, and the town of Everett with reference to a water supply from the Shawsheen River, — a subject which required more than two months of steady work of the office force for its investigation, — and the application of the city of Brockton for advice as to the best method of disposing of its sewage, which required many days to be spent in and about that city, aided by its engineer, to determine as well as could be without actual surveys of each place, the best one for the disposal of the sewage upon land.

In the case of the city of Boston and the associated municipalities, which, as they are all supplied by the city of Boston with water from the Mystic works, I will call the Boston Water District, the first question submitted to your Engineer was in regard to the length of time the present sources of water supply, when fully developed, would serve Boston alone, or this whole district.

This was in either case a problem of three principal elements.

1. The population to be supplied.
2. The quantity of water to be allowed per inhabitant.
3. The capacity of the sources when developed.

In considering the first element of the problem, tables and diagrams were prepared showing the population from 1810 to the present time of the present territory of Boston; of the Boston Water District; of the territory of Boston proper, excluding all annexation, and consequently East and South Boston; of the territory in 1865, prior to the annexation of Roxbury, Dorchester, West Roxbury, Charlestown and Brighton; and of the Metropolitan District, comprising all cities and towns within a limit of about nine miles from the State House.

The past experience of the first two districts indicated a somewhat definite law governing the rate of increase, and was thought to be the best basis for future estimates. The others were considered to show the relations of the first two to the whole Metropolitan District and the effect of restricted territory upon the future rate of growth.

The future population as estimated was much smaller than any previous estimates that have been made in connection with the Boston water supply, either by those favoring or opposing the addition to it of the Shawsheen River.

It has been customary to estimate the growth of cities by percentages of increase in a given time, and to consider these percentages as somewhat nearly constant. This is what might naturally be expected if the increase in population was wholly due to the excess of births over deaths ; but in Boston and the Boston Water District, this rule does not appear to apply, since the growth in each five-year period from 1840 to 1885 was approximately constant in *numbers* and not in *percentages*. This result is due, in part, to the relation of emigration to immigration, and to the encroachment of the business upon the residential districts, taken in connection with the somewhat limited area of the latter. I refer to this area as being limited, not because it would not hold the whole growth of the Metropolitan District for many years, but because there is a much larger area near the city, which offers nearly equal attractions to those engaged in business in the city.

The effect of limited area in decreasing the rate of growth is strikingly shown when the population of Boston proper (excluding all annexation) is examined. In 1850 its population was 113,721 ; in 1855, 126,296, an increase of 12,575 in five years. From 1880 to 1885 the increase in five years was but 63. In the present territory of Boston the rates of increase, during the same five-year periods, were respectively 33,920 and 27,554 ; while in the Metropolitan District, outside of Boston, the corresponding figures were 21,040 and 37,214. These figures indicate that the slower rate of growth of Boston is due, largely, to its limited territory, the suburban municipalities absorbing a large share of the growth.

The possibility of the annexation of more territory was considered, but it was found impossible to predict its occurrence or its effect ; some of the places suitably situated for annexation having a limited water supply, and others an ample supply for a long time in the future.

The second element in the problem, namely, the quantity of water to be allowed per inhabitant, was one not easily answered. In the large cities of this country, from 61 to 154 gallons are used daily. Boston used 66 gallons in 1870, 91 gallons in 1883, and 74 gallons in 1886. On the last date measures for the restriction of waste were in force. Of the large cities, the smallest consumption, 61 gallons, is in Brooklyn, N. Y., and it contrasts more strongly with the 74 gallons used in Boston, when it is considered that systematic measures to restrict waste are in force at the latter place and not at the former. A very little consideration of the subject shows one important difference in the conditions of the two places. In Boston, in addition to the inhabitants, a large number of people coming from the suburbs use the city water during the day, while in Brooklyn the reverse is true. Both Boston and Brooklyn have adopted the policy of measuring water sold to large consumers; yet, from the reports of the two places, it was found that the metered water in the former place was equivalent to 18 gallons daily, per inhabitant, while in the latter it was only one gallon. Some of the large users of water, such as hotels and steam railroads, in a business centre like Boston, are found only in limited numbers in a city like Brooklyn, occupied chiefly by dwelling-houses. Correspondence with the Brooklyn authorities elicited the fact that many of the large consumers of water in that city had private supplies drawn from the ground, a thing which is not often practicable in Boston. Examinations of this kind showed that the legitimate present and future consumption of water in Boston could not properly be based, to any great extent, upon the experience of other cities, and it was, consequently, necessary to study carefully the present legitimate use of water in Boston, and its increase in the past. I will not refer to this portion of the investigation in any detail, but will mention that it was a very careful one, and it showed that while the present consumption of water in Boston could, after a term of years, be materially diminished by the business-like application of known methods of restricting waste, yet there was a legitimate *increase* in the amount of water used per inhabitant, which would probably cause the legitimate *use* to rise as high as the present consumption at the end of about thirty years.

The third element of the problem — the capacity of the sources when developed — could be more accurately answered than ever before, because of extended surveys, then about completed, made by the city of Boston for the purpose of ascertaining the capacity and cost of storage reservoirs required to develop these sources. With these new data, and the records of the very dry years of 1880 and 1883, the result was obtained that the Sudbury and Cochituate sources would yield for the purposes of the city water-supply fully 50,000,000 gallons per day. This quantity was based upon the record of years so much dryer than any other in the history of the Boston Water Works, that it did not seem necessary to make further allowance for the occurrence of two such years in succession, or for the occurrence of still dryer years, particularly as many years would elapse before the consumption of water would approach this quantity, and there would then be further experience to draw from.

Having drawn from these three elements of the problem the solution that the two sources mentioned (the Mystic being excluded) would probably supply Boston until 1912, and the Boston Water District until 1926, estimates were made of the probable and comparative costs of supplying for a term of years, with water from the Shawsheen or from the Sudbury and Cochituate works, the district now supplied with water from the Mystic works; the results being very favorable to the substitution of the Sudbury and Cochituate sources.

Examinations of Water Supplies and Inland Waters.

An appropriation providing for a comprehensive examination of the water supplies and inland waters of the State was made by the Legislature April 25, 1887. The work was begun soon after this date.

These examinations consist chiefly of monthly analyses of water from all the water supplies of the State, and of the more important rivers and other inland waters, supplemented at varying intervals by the examinations of a bacteriologist, and of a biologist who examines the grosser forms of microscopic life in the waters.

It has been the duty of your Engineer in connection with this work to make himself familiar with the various water supplies of the State; to determine under the general direction of your Board where samples of water should be taken; to arrange for their regular and systematic collection, and to gather information about all physical characteristics of the different water supplies, such as temperatures, volumes flowing in the streams, heights of water in the reservoirs, etc.

The results of the chemical and other examinations of the waters, when reported to the Board, have been in the custody of your Engineer, who has carefully studied them with the view of determining from his own stand-point in which directions new examinations could profitably be instituted, or those being made extended, diminished or discontinued.

At the beginning of the work, which has thus been outlined, the following circular and blank for returns were prepared: —

OFFICE OF STATE BOARD OF HEALTH,
13 BEACON STREET, BOSTON, May 23, 1887.

To ——— ———.

The State Board of Health intends to make monthly analyses for the ensuing year of waters used for domestic supplies within the State, and, in connection therewith, desires to obtain general information respecting the several water supplies. It, therefore, requests that you will send such printed information as you can; particularly reports describing the construction of your works, the occurrence of any unusual tastes, or growths of vegetation in or upon the water, or any general disease affecting the fish in the streams, ponds and reservoirs.

An answer is requested to such of the questions in the accompanying blank as are applicable to your works.

The library of the Board now contains the reports mentioned below.

Respectfully yours,

F. P. STEARNS,
Engineer State Board of Health.

COMMONWEALTH OF MASSACHUSETTS,
STATE BOARD OF HEALTH.

Please fill out such portions of this blank as are applicable to your works, and forward to F. P. Stearns, Engineer State Board of Health, 13 Beacon Street, Boston.

Some of the blanks have been filled from information now in the possession of the Board: please correct if wrong.

DATE, ——— ——— 188 .

1. Name of city or town.
2. Population, 1885.
3. Date when works were built. (If not all built at one time, state what additions were made, and when.)
4. By whom are works owned?
5. Source or sources of water supply.
6. Area of water-shed supplying such source or sources.
7. General geological and topographical character of the water-shed.
8. Mode of supply, whether by gravity or pumping, and whether distributing reservoir or tank is used.
9. General description of storage and distributing reservoirs, — natural or artificial, how constructed, area of water surface, capacity, character of bottom, amount of shallow flowage, etc.
10. Does all water pumped go through the distributing reservoir or tank?
11. What portion of the water pumped goes into the distributing reservoir?
12. Whether or not the water is delivered into the distributing reservoir at one side and drawn out at the other.
13. Number, kind, size and depth of wells used as sources of water supply.

14. Describe filter galleries or basins, and connections, if any, with stream, pond or reservoir.
15. Average daily capacity of works in dry year.
16. Daily average consumption.
17. Number of persons using the water.
18. Is water supplied to any one outside of your town or city?
19. Material of distributing mains.
20. Material of service pipes.
21. Does the water supply receive sewage, drainage from factories (mentioning kind), or other pollutions?
22. If there have been any bad tastes in the water, or excess of vegetable growth, or if the fish have been generally affected, and such occurrences are not fully described in printed reports, please describe the same and the remedy adopted, if any.
23. Have analyses of water from the present source been made? By whom? When? If not given in printed reports, please furnish copy of same.
24. Have records of the temperature of the water been taken in the past? If not printed, will you furnish copies if blanks are sent?
25. Will you keep records of the temperature of water in the future, if a thermometer and blanks are furnished?
26. Will you furnish samples of water for analysis each month, and forward at stated times by express, if bottles are supplied?
27. To whom shall future correspondence be addressed?
28. Name and address of collector of samples.
29. Name of Express Co.
30. Name of person furnishing this information.

Beginning the first of June, 1887, every public water supply in the State was visited and examined by your Engineer, or one of his assistants; places for taking samples of water were chosen, and the methods to be followed were explained to those who were to take them. Arrangements were also made for having daily records of the temperature of water taken at many places and sent monthly to this office.

From these returns it is found that all of the twenty-three cities in the State, and 103 out of a total of 327 towns, are wholly or in part provided with a public water supply.* This number excludes several towns in the western part of the State, where a limited number of families are supplied through a small pipe, by some individual or company, from a spring or stream on the neighboring hills; also others, where water is pumped from a manufacturing establishment to the dwellings of the operatives in the vicinity.

* Four towns, for which water-works are being constructed and are so nearly finished that they will be in operation the greater part of the coming year, are included in this and subsequent statements.

In Table No. 1 the number of cities or towns, having or not having public water supplies, are classed by each 500 of population, up to 6,000, according to the census of 1885. All places having a population of 6,000 or more, which includes all of the cities, now have a public water supply.

TABLE NO. 1.

POPULATION.	No. of places of given population having a public water supply.	Total population of places in preceding column.	No. of places of given population not having a public water supply.	Total population of places in preceding column.
Under 500	1	451	22	7,530
500–1,000	3	2,437	69	52,751
1,000–1,500	4	5,346	39	47,086
1,500–2,000	8	13,559	33	57,305
2,000–2,500	10	22,057	21	47,233
2,500–3,000	5	14,254	18	49,706
3,000–3,500	2	6,155	8	25,534
3,500–4,000	13	49,441	6	22,598
4,000–4,500	12	51,763	5	21,318
4,500–5,000	7	33,312	1	4,555
5,000–5,500	3	15,633	1	5,436
5,500–6,000	4	23,036	1	5,711
Above 6,000	54	1,357,934	–	–
Totals,	126	1,595,378	224	346,763

From the totals given in this table it will be seen that although but few more than one-third of the whole number of cities and towns in the State have a public water supply, yet the total population of the places supplied represents 82 per cent. of the population of the State. This estimate of population represents the whole number of persons in the municipalities supplied, and is consequently somewhat, though not very much, in excess of the number of persons who can avail themselves of a public supply. By further examination of the table it will be observed that there are but three towns having a population exceeding 4,500 that are not supplied, and that where the population exceeds 3,500, the majority are supplied, while below this limit the reverse is true.

There are some important towns where the supply is limited to but one of several villages.

There are in the State 123 sources of public water supply, counting as a source each separate system of water works, and also each of the sources used in connection with any particular system, when essentially different in character. This does not agree exactly with the number of municipalities supplied, since in many cases a city, town, or company supplies several places, while in others a city or town has several sources of supply.

To indicate the nature of the sources, they may be divided into fifty supplying ground water, and seventy-three supplying surface water. Further classification of the sources may be made as follows: —

Ground-water Sources.

Springs,	16
Large wells,	16
Tubular wells,	7
Filter galleries,	7
Filter basins,	4
Total,	50

Surface-water Sources.

Artificial storage reservoirs,	36
Natural ponds,	32
Streams,	5
Total,	73

The line of separation between the different classes is somewhat indefinite. A filter gallery or well on the banks of a stream may each furnish water of identically the same character, while another well may furnish the water of a natural spring which it has replaced. Natural ponds by having their level raised may flow extensive meadows, and so become less satisfactory reservoirs than those that are wholly artificial. Tubular wells are frequently sunk in the bottoms of large wells or filter basins with the view of increasing the supply of water; and in other ways the classification is somewhat complicated, yet it furnishes a fair idea as to the sources from which the water supply of the State is obtained.

The cities having a population of more than 25,000 each, thirteen in all, get their supply from surface sources. Of the cities and large towns having a ground-water supply may be mentioned the following: —

City or Town.	Population in 1885.
Newton,	19,759
Waltham,	14,609
Newburyport,	13,716
Quincy,	12,145
Woburn,	11,750
Milford,	9,343
Brookline,	9,196
Hyde Park,	8,376

In Table No. 2 the various water supplies are classified by dates. The dates given are those when a modern public water supply was first introduced into a city or town.

Table No. 2.

YEARS.	Increase in number of places supplied during the given time.	Increase in number of places supplied per year.
Previous to 1850,	6	–
1850–1859,	4	0.4
1860–1869,	10	1.
1870–1874,	29	5.8
1875–1879,	15	3.
1880,	4	4.
1881,	6	6.
1882,	3	3.
1883,	6	6.
1884,	7	7.
1885,	18	18.
1886,	5	5.
1887,	13	13.
Total,	126	–

This table shows the activity in water-works construction since 1870. Before that time the total number of municipalities supplied was twenty, or less than one-fifth of the present number. Nearly one-half of the whole number have obtained their supply since 1880. The table takes no account of the many important additional supplies provided in many cases.

Of the 23 cities in the Commonwealth, 20, having a total population of 1,030,282, own their water works; while 3, having a total population of 57,214, are wholly supplied by private companies.

Of the 103 towns having a public water supply, 50, having a total population of 285,086, are supplied from their own works, and 53, having a total population of 222,796, by private companies. In this classification no account is taken of secondary supplies of small importance which exist in many places. The total population of the cities and towns owning their own works is 1,315,368, against 280,010 for those supplied by private companies.

About 200 samples of water collected from the existing water supplies of the State, and from 36 places on 17 rivers and ponds, are received monthly at the laboratory, in addition to a varying number collected as occasional specimens from other places or in connection with special investigations of new sources or existing works. Daily records of the temperature of the water at 50 places, and of the heights of water and other information needed to make an approximate estimate of the amount flowing in the rivers at 19 places, are taken by water-works and mill superintendents, or special observers, and are forwarded monthly to this office.

Schedules are prepared each month to show the day on which each sample of water should be collected, and are so arranged that the samples will reach the laboratory at a nearly uniform rate during the first five week-days of each week, in order to permit them to be analyzed promptly when received. The schedules are also arranged so that waters having some relation to each other shall be collected on the same day or, in the case of rivers, after such an interval of time as will allow the water to flow from one sampling place to another.

The willing co-operation of the water-works superintendents and others, and their readiness to collect and forward samples of water and to take such observations as we have desired, have added greatly to the value of the work done and have decreased the labor of this department; yet the tabulation and examination of the analyses and returns, the occasional visits to the different water works for further information or to collect samples, the special investigations made, and the very large amount of correspondence necessarily incident to such work, together with other work not connected with the water examinations, have kept the force employed in this office extremely busy.

In arranging in the beginning where samples of water should be taken it was the aim to get them in such a way that the chemical analyses would not only furnish a standard for future comparisons, but that they should show in addition general laws affecting the purity of water supplies. With this in view samples were taken of ground waters from filter galleries, wells and basins, and of surface waters in neighboring ponds or streams, to determine the effect of such filtration as might take place; other samples were taken to show the effect of storing ground or surface waters in open distributing reservoirs or in open or closed water towers; others the effect of continuous filtration through a thin layer of sand or gravel; others the comparative quality of water taken from the surface, mid-depth and bottom of a deep reservoir; others a comparison between water entering a storage reservoir and after standing in it; and others the effect of aeration caused by the flow down a long steep brook of water previously stored in a reservoir.

Many results have already accumulated, and an examination of them indicates that in addition to the great fund of scientific knowledge which they will furnish, much of practical value to those designing and superintending water works may be learned from such comprehensive work.

It is not proposed at this time, when the series of examinations of the waters is incomplete and all seasons of the year have not been included, to make any extended statement of the results found; some, however, are so well indicated and so important that it seems desirable to report them as they now appear.

When the first filter galleries were built beside the rivers or ponds it was expected to get water filtered from the neighboring surface supply. It was found, however, that the water from the galleries differed very much in chemical analysis, temperature and appearance from the surface waters, and before pumping stood at a higher level.

From all this it was concluded that the water did not come from the neighboring pond or stream but from the land side.* Two instances are given in Table No. 3 of analyses of surface waters and of the filtered or ground waters beside them.

* Where water from the land side is mentioned in this report, it refers only to water derived from rainfall soaking directly into the ground, and not to that which frequently enters a filter gallery or well from the land side, having come by a circuitous course from the adjoining pond or stream.

TABLE No. 3.

Analyses of Samples of Water taken from a pond and from a filter gallery beside it, also from a river and from driven wells near its banks.

[Figures express parts per 100,000.]

	Pond.	Filter Gallery.	River.	Driven Wells.
Date of taking sample, .	July 11,'87.	July 11,'87.	July 11,'87.	July 11,'87.
Date of examination, .	" 13, "	" 13, "	" 11, "	" 11, "
Sediment, . . .	Light brown flocky.	None.	None.	None.
Turbidity, . . .	Decided.	None.	Slight.	None.
Color,*	0.4	None.	1.0	None.
Odor, cold, . . .	Peculiar and offensive.	None.	Faint.	None.
Odor, hot, . . .	Strongly offensive and persistent.	None.	Very faint.	None.
Total residue, . . .	12.74	11.70	5.95	6.10
Loss of residue on ignition,	2.17	1.95	1.75	0.75
Fixed residue, . . .	10.57	9.75	4.20	5.35
Odor and characteristic on ignition, . .	Strongly peaty and somewhat disagreeable.	Disagreeably irritating and acid.	Strongly peaty.	Peculiar and acid.
Free ammonia, . .	0.0042	0.0012	0.0069	0.0000
Albuminoid ammonia, .	0.0803	0.0022	0.0432	0.0010
Chlorine, ...	2.94	2.29	0.58	0.81
Nitrogen as nitrates, .	0.003	0.034	None.	0.039
Nitrites, ...	None.	None.	None.	None.
Hardness, . . .	5.57	5.57	–	3.38
Temp. of water at source,	About 77°	About 52°	76°	51°

From an examination of this table it will be seen that there is a very decided difference in the character of the two classes of waters in nearly every respect except in residue and chlorine.

* Colors are designated by a scale of figures increasing with the increase of color: 1.0 represents a distinct yellowish brown when seen in a depth of five or six inches; 2.0 represents a decided yellowish brown. Odor is obtained by agitating the water in a closed bottle, about half full, and then smelling the air.

Sediment, turbidity, color and odor (cold and hot) do not appear in the water taken from the ground, the ammonias are very much diminished, and the nitrates are increased. The temperature of the ground water was also much less at the time of year when these samples were taken.

There are several reasons why it seems probable that water drawn from filter galleries, or by other means from the ground in the vicinity of bodies of surface water, comes to a large extent from the latter source; and it was thought that if this could be shown to be the case, and it could be shown at the same time that the filtered water lost the general characteristics of surface waters and assumed those of ground water derived from rainfall soaking into the ground, the knowledge would be of much practical value to those locating or enlarging a ground-water supply.

To settle the question, if possible, a special case was chosen for thorough investigation where the supply for a town was pumped from a filter gallery, distant about 130 feet from the shore of a pond.

The amount of water pumped from this gallery during the year equals a daily average of about 900,000 gallons. The pumps are operated during each week day for about ten hours, no pumping being done on Sunday.

The level of the water in the filter gallery remains permanently below the surface of the pond, lowering when the pumps are in operation and rising when they are stopped. These fluctuations vary in extent at different times of the year. In December, 1887, the water rose to within about one foot of the level of the pond on Monday mornings, when the pumping had been discontinued for thirty-eight hours, while other mornings it was six inches lower. In the evening it was about four feet below the pond.

The mean of seven analyses, made monthly from June to December, 1887, of the water of this pond and of the filter gallery beside it, are given in Table No. 4.

In the last column of the table is given a mean of corresponding analyses of water from an open distributing reservoir, into which water is pumped from the filter gallery. Reference will be made to this in a subsequent portion of this report.

TABLE No. 4.

Mean of Seven Analyses made monthly from June to December, 1887, of the water of a pond, a filter gallery beside it, and an open distributing reservoir into which water is pumped from the filter gallery.

[Figures express parts per 100,000.]

	Pond.	Filter Gallery.	Open Distributing Reservoir.
Sediment, ...	Some.	None.	A little.
Turbidity, ...	Considerable.	None.	Some.
Color,*	0.4	0.0	0.0
Odor, cold, ...	Considerable.	None.	Some.
Odor, hot, ...	Considerable.	None.	Some.
Total residue, . . .	13.79	12.06	11.81
Loss of residue on ignition,	2.19	1.54	1.57
Fixed residue, . . .	11.60	10.52	10.24
Free ammonia, . . .	0.0149	0.0014	0.0032
Albuminoid ammonia, .	0.0480	0.0028	0.0105
Chlorine, ...	3.74	2.40	2.30
Nitrogen as nitrates and nitrites, ...	0.022	0.031	0.017
Nitrites, ...	Present twice.	None.	Present once.

This particular source of water supply was chosen in preference to any other because the pond was artificially salted by the drainage from manufacturing establishments on its feeders; so much so that it contained about ten times as much chlorine (one of the components of common salt) as most ponds at the same distance from the sea and not affected by drainage.

The value of an abnormal amount of salt in a surface water for determining the source from which water comes to a filter gallery lies in the fact that it is a stable chemical compound, and is not removed when the water containing it in solution is filtered through the ground.

In proof of the latter part of this statement numerous instances may be cited where analyses of filtered and unfiltered water show

* For scale of color see foot note, p. 79.

the same amount of chlorides. The most conclusive proof, however, is furnished by the careful and extended experiments made at the Massachusetts Institute of Technology by the late Prof. Wm. Ripley Nichols and described by him in a paper * presented to the Boston Society of Civil Engineers, April 16, 1884.

It is, of course, possible for water passing through ground containing salts to dissolve them and so increase their proportionate amount in the water; and in the case of filtration from a pond or stream into a filter gallery the latter may contain more or less salt than the former, owing to the admixture of water coming from the land side.

By reference to Table No. 4 it will be observed that the water of the filter gallery contains 2.4 parts of chlorine per 100,000, or about six times as much as is usually found in water at this distance from the sea. This large quantity may be accounted for in two ways: either by the filtration of water from the pond, or by some abnormal condition of the soil which makes the water from the land side rich in chlorides. To determine whether or not the water from the land side presented this unusual feature, samples of water were collected from an unpolluted brook and pond in the vicinity, and from several pits dug deep enough to collect water coming to the filter gallery from the land side. In the samples of the water from the pond, brook, and three of the pits in which the water stood at a *higher* level than in the pond, the amount of chlorine varied from 0.25 to 0.45 in 100,000, averaging 0.37, or less than one-sixth of the amount in the filter gallery. Just what the figures that have been given mean may be more easily understood by showing the results in a different form.

The average amount of water pumped daily from the filter gallery may be stated in round numbers as 900,000 gallons or 7,500,000 pounds.

The chlorine in the water is found to be 2.4 parts per 100,000, equivalent to 180 pounds of chlorine in the daily pumpage.

If it is assumed, as is probably the case, that all the chlorine in the water is combined with sodium in the form of common salt, it can be shown from the relation which these two components always bear to each other that the total amount of salt pumped per day is 297 pounds. An equivalent amount of water derived from the land side would contain only 46 pounds of salt, while the same amount of water derived wholly from the pond would contain 462 pounds.

These figures not only show that the water in the filter gallery is a mixture of the waters from the pond and the land side, but

* On the Filtration of Certain Saline Solutions through Sand: Journal of the Association of Engineering Societies, vol. iii., p. 139, 1884.

they permit a fairly good estimate to be made of the proportion which must come from each source to produce the degree of saltness equivalent to that found in the water from the gallery.

Such an estimate shows 60 per cent. of the water to have come from the pond and 40 per cent. from the land side, during the seven months under consideration.

Other investigations were made to determine the source supplying water to this gallery, and they may be mentioned in a subsequent report when the investigations of the whole year are completed. They were generally corroborative of the results here given.

Before leaving the subject of the source of this water supply it may be well to state that it is improbable that much of the water derived from this pond comes through the comparatively narrow strip of ground separating the pond from the gallery; in fact, the statement may be made in a general way that in the bed of a stream or pond the spaces between the grains of sand and gravel usually become choked up with silt and vegetable matter to such an extent that little water will pass through any given square foot of surface; and it is only where a large area of bed overlies or adjoins the porous stratum that it is safe to expect that a large supply can be obtained by filtration.

When the water is once in a coarse gravel stratum of considerable extent it may find its way readily to a filter gallery even from a long distance. That some of the water came from a long distance to the gallery in the case specially investigated was proved by test pits dug near the shore across an arm of the pond and 1,000 feet from the gallery.

The water surface in these pits stood several inches below that in the pond, fluctuated with the change of level in the filter gallery, and the water from them contained more than the normal amount of chlorine found in the ground water in this vicinity, showing that some of the pond water passed through these pits on its way to the gallery.

Coarse gravel will hold in its interstices about 30 per cent. of its volume of water, and where the gravel beds are extensive the large body of water contained in them has to move slowly towards the filter gallery to furnish the amount pumped, so that some of the water may be weeks or even months in its passage through the ground.

Upon examining the relative analyses of water from the pond and filter gallery, as given in Table No. 4 on page 81 it will be observed that in most features the difference between the two cannot be accounted for by the mixture of water from the pond and land side in the proportion before stated. Sediment, turbidity, color and odor (cold and hot) which are very noticeable in the pond water, are absent in the water from the filter gallery. The residues and chlorine do not show a greater difference than can be accounted for by the mixture of the waters.

The change in the ammonias is the most noticeable feature, the gallery water containing but one-eleventh as much free ammonia and one-seventeenth as much albuminoid ammonia as that from the pond. The greater amount of nitrogen as nitrates and nitrites (nearly all nitrates) in the gallery water, might be accounted for by the mixture of the waters, but it is more probable that the increase is due to the oxidation and consequent purification of the decomposing nitrogenous matters indicated in the pond water by the presence of the ammonias.

The water of the pond is shown by the analyses to be entirely unfit for drinking, while water from the gallery analyzes well in many respects,but is to be viewed with some suspicion on account of its source.

In addition to the chemical analyses of these waters, other examinations were made to determine whether bacteria and the grosser forms of microscopic life (algæ, etc.) found in the pond water were removed by its filtration through the ground to the gallery.

The number of bacteria found per cubic centimeter in the pond water Oct. 12, 1887, was 70; in the water from the gallery, 13. On the 12th of December, 1887, the numbers found were respectively 65 and 1. The mean of these results shows that the gallery water contains but one-tenth as many as that from the pond. The species were not determined, and it is not known whether the bacteria found in the gallery were developed there or whether they came through the ground. In many other instances in this State, where comparisons have been made of the number of bacteria in surface waters and in the filter galleries or wells beside them, much greater differences have been found than in the cases above given; an extreme instance showing a ratio of 16,500 to 2.

The bacteria found in all of these cases may have been and probably were harmless, but since the best known of the pathogenic bacteria are no smaller, it seems fair to assume that the means which will remove one will remove the other.

That filtration through even a moderately thin layer will, under proper conditions, remove a very large percentage of the bacteria from water, has been very definitely shown by the experiments of Dr. Percy F. Frankland* by practical experience in the filtration

* Water-purification, its Biological and Chemical Basis, by Percy F. Frankland, Ph.D., etc.; Proceedings of the Institution of Civil Engineers, vol. lxxxv., London, 1886.

of the water supplies of London and Berlin, and by recent experiments at the Lawrence Experimental Station, described in the report of the Board which this accompanies. In fact, the efficiency of the Berlin filter beds is now determined by the percentage of the bacteria which they will remove from the water.

The examination of the waters of the pond under consideration, for microscopic growths other than bacteria, showed the presence in abundance of several species of algæ, some of which were gelatinous forms which readily decompose and produce disagreeable tastes and odors in the waters; other growths were present in small numbers. The water of the filter gallery did not contain any of the species of organisms found in the pond, though it did contain a few other species, — one in some abundance.

These results are in accordance with those obtained from other water supplies somewhat similarly situated.

In the warmest weather in summer the temperature of the water of the pond was as high as 80° Fahrenheit, while that of the filter gallery was about 52°.

As a general result of these special examinations, corroborated in many respects by similar results found at other water supplies in the State, the following practical conclusions may be drawn: —

That it is practicable in many instances to obtain a supply of water from a bed of porous gravel adjoining an unfailing pond or stream, without reference to the amount of water that may be obtained from the land side.

That where the soil does not contain soluble matters to injuriously affect the water, it will, when so obtained, be much purer by chemical and biological standards, will be much cooler in summer, and in all sanitary and commercial features will be much better than water taken directly from the pond or stream.

That since it is impracticable in many cases to get an entirely satisfactory supply of water, it is preferable to obtain a groundwater supply by filtration from a surface source that is somewhat objectionable, rather than take surface water directly from a source that is some degrees less objectionable.

There are other conclusions which ought not to be drawn to which it is equally well to call attention.

It should not be inferred that the results above indicated will be obtained where only a thin layer of sand or gravel intervenes between the surface source and the filter gallery, and the filtration is continuous, since examinations, in several instances, of water filtered under such circumstances have shown it to be worse than that which had not been filtered: nor should it be inferred that it is safe to take a supply by filtration from a seriously polluted body of surface water, since, while the chemical analyses show by far the larger portion of the decomposable organic matter indicated by the ammonias to have been removed by filtration, yet the small amount remaining may be of a harmful nature, and there is no definite assurance that the purifying powers of the soil may not at times be overtaxed.

It may properly be urged as an objection to seeking a supply of ground water that the quantity to be obtained cannot be told with the same certainty as that from a visible supply. The quality of the water, however, makes it desirable to secure such a source when practicable; and while the exact amount of water cannot be ascertained in advance of the actual construction and test of the well or filter gallery, a competent engineer, experienced in these matters, can form a judgment upon which much reliance may be placed.

In Table No. 4, on page 81, in addition to the analyses of the waters of the pond and the filter gallery, already discussed, the third column gives the mean analysis of the water in the open distributing reservoir.

When the pumps are in operation, the surplus water goes to this reservoir, and nights and Sundays when the pumps are stopped it furnishes the water used. Complaint is made in summer by those using the water that it tastes badly when it comes directly from the reservoir, while that coming directly from the filter gallery does not.

The chemical analyses show that in nearly all other respects the water has seriously deteriorated in quality by storage. Sediment, turbidity and odor make their appearance in the reservoir water. Free and albuminoid ammonia, indicating the presence of decomposing or decomposable nitrogenous organic matter, have greatly increased, while the nitrogen in the form of nitrates has decreased, apparently by the passage of a portion of the nitrogen from the inorganic to the organic condition.

A cause for this and a practical remedy appear to have been found by Mr. G. H. Parker, the biologist of the Board, charged with the examination of water for organisms other than bacteria, and are contained in his accompanying report.

The remedy which he proposes (the entire exclusion of light to stop the growth of vegetation) has been applied in the case of the iron storage tank of the Brookline high service, and the serious trouble from bad taste, which previously existed, has entirely ceased; moreover, the chemical purity of the water in the tank is as great as at the source.

A result corresponding to the last statement has been found under similar circumstances at several other places in the State similarly situated.

The marked deterioration, as determined by chemical analyses, of ground water stored in large open reservoirs, is a feature in all cases that have been examined. The amount of deterioration is somewhat variable.

Table No. 5 has been prepared to show the change due to storage that has taken place in six water systems during six months. The general result is the same as in the special case before given. The increase in the ammonias is even more marked.

Table No. 5.

Mean of Analyses made monthly from June to November, 1887, of the waters of six filter galleries or wells and of the corresponding open distributing reservoirs into which the water is pumped from the filter galleries.

[Figures express parts per 100,000.]

	Filter Galleries or Wells.	Open Distributing Reservoirs.
Sediment,	None.	A little.
Turbidity,	None.	Some.
Color,	None.	None.
Odor, cold,	None.	Some.
Odor, hot,	None.	Some.
Total residue,	8.86	8.82
Loss of residue on ignition,	1.19	1.39
Fixed residue,	7.67	7.43
Free ammonia,	0.0004	0.0011
Albuminoid ammonia,	0.0017	0.0117
Chlorine,	1.13	1.09
Nitrogen as nitrates,	0.088	0.064

In a majority of cases water from such reservoirs has, at times, tasted badly. In but few cases has trouble of this kind been reported from water stored in iron tanks; but these few cases, and particularly the one already mentioned, make it desirable to exclude the light from any to be built in the future, or from any that give trouble at the present time. Where water from a pond or other surface source is pumped and stored in an open distributing reservoir no marked change in the analysis takes place.

Respectfully submitted,

F. P. STEARNS,
Chief Engineer.

OFFICE OF THE STATE BOARD OF HEALTH,
13 BEACON STREET, BOSTON, Jan. 9, 1888.

APPENDIX A.

REPORT OF THE BIOLOGIST.

CAMBRIDGE, Jan. 4, 1888.

To H. P. WALCOTT, M. D., *Chairman State Board of Health.*

Sir: — The following report contains a brief preliminary account of the organisms, excepting the bacteria, found in certain potable ground waters. The influence of the organisms on the water and a remedy for their deleterious effects is discussed at some length. A fuller consideration of this topic and an account of the organisms found in surface waters will be deferred till a later report. As there is considerable variation in the plans of the six water systems examined they will be treated separately.

Brookline. — The source of supply for the water of the town of Brookline is a filter gallery lying parallel with and near to the Charles River. The gallery is completely closed and the water which is in perfect darkness is pumped from this gallery to two storage reservoirs, one an iron tank for the high service of the town, and another the open reservoir for its general service. The high service tank and open reservoir were the places where the water first met the light. From these two reservoirs the water is conducted by distributing mains to the town.

The quality of the water delivered in the town was at times far from satisfactory. A strong taste and odor were often present in it, and these were the more marked when it was contrasted with the water at the pumping station. This latter was clear and completely free from disagreeable taste or smell.

An examination of the microscopic contents of the water in the open reservoir was made July 14. The water was found to contain five species of green algæ, — Pediastrum, Eudorina, Volvox, Staurastrum and Asterionella, the last two of which were abundantly represented. In addition to these there were a few filaments of a blue-green alga, Oscillaria, and the decomposed remains of an entomostracan (water flea). As the green algæ were the only organisms abundantly present in the water and as there was no source of contamination, other than the contained organisms, it was suggested that the disagreeable taste and smell was in the main due to the minute green plants.

The question then naturally proposed itself, was there any means of ridding the water of these plants? It has been known for some time that the life of all green plants is dependent upon certain materials and surroundings. In order that a green plant should continue to live and grow it must have, in addition to a few less constant materials, some nitrogenous compound, water, carbon dioxide and oxygen. These in themselves, however, are not sufficient to nourish the plant; they can be utilized only in the presence of sunlight. So exacting is this latter requirement that any green plant destitute of food stored in its own tissues, if placed in perfect darkness, dies at once.

With this in mind as a working theory, it was suggested that the high service tank at Brookline should be completely covered and all light excluded. The tank was emptied, cleaned and a double roof with eaves was placed on it. This was impervious to the light and from time to time was examined to ascertain that no cracks had opened. Water was introduced and on October 7 a second microscopic examination was made.

At this examination samples were taken at the pumping station, high service tank and open reservoir. The method of taking the samples is as follows: In cases where a faucet is available a stout cotton cloth is tied over the nozzle and about seven gallons of water are strained through it. This amount of water is sufficient for an ordinary examination and can be passed through the cloth in as short a time as fifteen minutes, without producing pressure enough to drive the organisms through the meshes.

In cases such as the open reservoir, where no faucet was available, a piece of cloth was stretched on a net frame and carried through the water. Such sample cloths should be placed in clean bottles previously rinsed with water from the same source as that for the sample. The contents of the cloth should be examined as soon after collection as possible, certainly within thirty-six hours. This limit is partially dependent upon temperature; in cold weather the cloths can be kept longer than at warmer periods. If the cloths cannot be examined at once they should be dried shortly after the collection is made, and in this state they can be preserved for months. When it is desirable to examine these dried cloths they can be moistened with distilled water. In the case of the Brookline water all the samples were examined while fresh.

The sample cloth from the pumping station showed no green algæ whatever. As the water in this portion of the system is in perfect darkness, the absence of green algæ agrees well with the theory. Several filaments of Leptothrix, insignificant in amount, were all that was found. The water was clear and devoid of disagreeable smell or taste.

The sample cloth from the open reservoir showed as previously an abundant supply of green algæ, a few representatives of the genera Pandorina and Staurastrum, an abundance of two species of diatoms and of one species of Anomopedium, with Raphidium and Volvox represented in still greater abundance. The water was slightly cloudy and had a very strong taste and decidedly fishy smell.

The sample cloth from the high service tank, now completely darkened, contained only one specimen of green alga, Closterium. This may possibly have been on the nozzle of the faucet, although this was washed before the cloth was put on. In addition to the alga there were several filaments of Hypheothrix which were probably growing in the tank. These, however, like the Leptothrix of the sample from the pumping station were insignificant in amount. The water from the high service tank was now free from odor and taste, and for all practical purposes as good as that pumped at the filter gallery.

From these observations it seems fair to conclude that since the unpleasant taste and smell in the water disappear with the disappearance of the green algæ, these latter are the cause of the taste and smell, and that any means by which the light is excluded from the storage reservoirs, filter basins, etc., will be sufficient to prevent the growth of green algæ.

What has been said applies only to the green algæ, and it is very natural for one to ask are there not other forms of vegetable or animal life which may adapt themselves to darkened chambers and in time become sources of contamination for the water. The possibility of this has already been suggested by the fact that in the closed tank and filter gallery two plants, Hypheothrix and Leptothrix, have been noticed. Could not these multiply to such an extent that in time they would become as noxious as the green algæ?

Before answering this question, we must glance for a moment at the relation which organisms sustain to their supply of food. All organisms depending upon the way in which they acquire their nutriment can be divided into two groups. The first group includes those which manufacture their food from certain simple chemical compounds. In order to carry on this work they must have some source of energy; this they find in sunlight. This group includes all green plants. The members of the second group, the animals and such plants as contain no green coloring matter, do not manufacture their own food, but nourish themselves by feeding directly or indirectly on organisms of the first group. For instance, man is a member of the second group; his food comes from two sources, other animals and green plants. At first sight the former might seem a source of food independent of green plants, but a moment's reflection will show that the animals used for nourishment are in their turn dependent for food either directly on green plants or on some other animal which in its turn is dependent on vegetation. Thus ultimately all animal food is derived from green plants. As sunlight is essential to members of the first group, so are representatives of this group or some product of their decomposition essential to the life of members in the second group. It is conceivable, then, that a member of the second group, an animal for instance, may live in perfect darkness so long as it is supplied with nourishment derived directly or indirectly from green plants, but as the exclusion of light destroys the green plant, so the exclusion of the green plant or its products of decomposition will destroy the animal.

Hypheothrix and Leptothrix, the two plants found in small numbers in the darkened tank and filter gallery, are members of the second group. They depend for their food upon partially decomposed products of members of the first group. Water which has percolated for a considerable distance through soil usually contains a low percentage of these products, and the presence of Hypheothrix and Leptothrix indicates that in this case that small amount is utilized as food. It will also be noticed that since the source of the Brookline water is free from any green growth the amount of nutriment contained in the water must be relatively small, consequently the Hyphcothrix and Leptothrix, being dependent upon this food for their growth, will probably never reach harmful proportions. This conclusion is further supported by the fact that in the Watertown system, to be described later, the Hypheothrix is found, and, although this system has been in operation for some years and the opportunities for growth are quite as favorable as in the high service tank at Brookline, the plant remains as inconspicuous at Watertown as at Brookline.

How far the conclusions obtained from the examination of the Brookline system are supported by other evidence will be seen from the following description of the five remaining systems.

Waltham (Nov. 23, 1887).— In the system at Waltham, the water is pumped from an open filter basin on the Charles River to an open reservoir, and is then distributed to the town. If we neglect the high service tank of the system at Brookline, this system is essentially like that of the last named town, except that the filter gallery is replaced by an open basin. With this difference we should expect to find green algæ not only in the reservoir but also in the filter basin. An examination of the water in the filter basin shows this to be true, for in addition to a large growth of Spirogyra, a partially attached green alga, seven species are found floating abundantly in the water.

Woburn (Oct. 12, 1887).— In the system at Woburn, the water is pumped from a filter basin not completely darkened into a main which distributes it to the town, and allows the surplus to flow back into a small reservoir. Our theory would predict a slight growth in the filter basin and an increased growth in the open reservoir. On examination the water from the filter basin contained a single specimen each of four species of green algæ and some filaments of Hypheothrix. In the reservoir two species from the gallery were found in abundance, and two others were also present. One, a Conferva, grew in large matted masses which, when dried, resembled the material of wasps' nests.

Newton (November, 1887).— The filter basin in this system is a long open canal running parallel to the Charles River. From this basin the water is pumped into a distributing main, and the surplus is stored in an open reservoir. From the exposed nature of the filter basin and reservoir we should expect in both an active growth of green algæ. Examinations of the water show that, besides the growth of Spirogyra, which occurs along the bottom of the filter basin, the water contains suspended in it six species of green algæ. Three of these were abundantly represented. The water in the reservoir contains nine species of green algæ, four of which are abundant. This increase in variety, and number of the species found in the reservoir over those in the filter basin, is perfectly consistent with a continued exposure of the water to sunlight.

Revere (Dec. 12, 1887).— At Revere the water from a series of driven wells is discharged into a chamber lighted by windows, and from this collecting chamber it is pumped into distributing mains. The overflow is collected in an open reservoir. Under these conditions a slight growth in the collecting chamber and an increased growth in the open reservoir might be expected. An examination of the water gives the following results: The water in the collecting chamber contains a few each of three species of green algæ; in the reservoir four species of green algæ are present; two of these are of the same species as those in the chamber. Of the four two are abundant and one is very abundant.

Watertown (Nov. 6, 1887).— The filter basin in this system is in part open so that one end receives diffused daylight. From this the water is pumped into the distributing main and the overflow is collected in a tank. This tank, although covered with a roof, has an air space above it into which a number of windows open. The filter basin receives fully as much light as the same structure in the Woburn system, and as this latter contained a few green algæ one would expect naturally a similar growth at Watertown. The tank, of course, receives much less light than an open reservoir, but there appears to be sufficient light to warrant the expectation of a few green algæ. An examination of the water in both the filter basin and tank shows only a few filaments of Hypheothrix. This at first sight may seem exceptional. By way of explanation, however, it may be said that in situations such as filter basins the presence of light only renders possible the life of green algæ but does not necessitate their growth. The Watertown system then may be one in which green algæ have not as yet made their way, but if once planted they might multiply there as elsewhere. It is noticeable, however, that owing to the small amount of light entering the filter basin and tank the growth of green algæ would probably never become conspicuous, not to say harmfully abundant. The water from this system as well as that from Revere has never been noticed to have any disagreeable taste or smell.

With this, the account of the examination of the ground waters is concluded. Excepting the conditions at Watertown, which have already been discussed, the four open reservoirs and four open filter basins examined all contained green algæ. When the algæ were abundant a disagreeable taste and odor characterized the water. The tank and filter gallery at Brookline, both completely darkened, contained no green algæ. In these two situations the water had no disagreeable taste or smell. From these facts it would appear that the green algæ are, in the main, the cause of the bad taste and smell in the water and that these plants are dependent for their existence on sunlight. It is therefore concluded that the complete exclusion of sunlight from storage reservoirs, filter basins, etc., is an efficient practical remedy for the deleterious effects of these organisms.

Respectfully submitted,

G. H. PARKER.

Commonwealth of Massachusetts.

[Chap. 274.]

An Act to protect the purity of inland waters.

Be it enacted, etc., as follows:

Section 1. The state board of health shall have the general oversight and care of all inland waters and shall be furnished with maps, plans and documents suitable for this purpose, and records of all its doings in relation thereto shall be kept. It may employ such engineers and clerks and other assistants as it may deem necessary: *provided*, that no contracts or other acts which involve the payment of money from the treasury of the Commonwealth shall be made or done without an appropriation expressly made therefor by the general court. It shall annually on or before the tenth day of January report to the general court its doings in the preceding year, and at the same time submit estimates of the sums required to meet the expenses of said board in relation to the care and oversight of inland waters for the ensuing year; and it shall also recommend legislation and suitable plans for such systems of main sewers as it may deem necessary for the preservation of the public health and for the purification and prevention of pollution of the ponds, streams and inland waters of the Commonwealth.

Sect. 2. Said board shall from time to time as it may deem expedient, cause examinations of the said waters to be made for the purpose of ascertaining whether the same are adapted for use as sources of domestic water supplies or are in a condition likely to impair the interests of the public or persons lawfully using the same, or imperil the public health. It shall recommend measures for prevention of the pollution of such waters and for removal of substances and causes of every kind which may be liable to cause pollution thereof, in order to protect and develop the rights and property of the Commonwealth therein and to protect the public health. It shall have authority to conduct experiments to determine the best practicable methods of purification of drainage or disposal of refuse arising from manufacturing and other industrial establishments. For the purposes aforesaid it may employ such expert assistance as may be necessary.

SECT. 3. It shall from time to time consult with and advise the authorities of cities and towns, or with corporations, firms or individuals either already having or intending to introduce systems of water supply or sewerage, as to the most appropriate source of supply, the best practicable method of assuring the purity thereof or of disposing of their sewage, having regard to the present and prospective needs and interests of other cities, towns, corporations, firms or individuals which may be affected thereby. It shall also from time to time consult with and advise persons or corporations engaged or intending to engage in any manufacturing or other business, drainage or refuse from which may tend to cause the pollution of any inland water, as to the best practicable method of preventing such pollution by the interception, disposal or purification of such drainage or refuse: *provided*, that no person shall be compelled to bear the expense of such consultation or advice, or of experiments made for the purposes of this act. All such authorities, corporations, firms and individuals are hereby required to give notice to said board of their intentions in the premises, and to submit for its advice outlines of their proposed plans or schemes in relation to water supply and disposal of drainage or refuse. Said board shall bring to the notice of the attorney-general all instances which may come to its knowledge of omission to comply with existing laws respecting the pollution of water supplies and inland waters and shall annually report to the legislature any specific cases not covered by the provisions of existing laws, which in its opinion call for further legislation. —[*Approved June 9, 1886.*

Acting under the provisions of this act, the State Board of Health is ready to consult with and advise the authorities of cities and towns and others, and to receive outlines of proposed plans from them, as provided in section 3 of chapter 274, Acts of 1886.